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USDA Forest Service  
Research Paper PNW-142

# DIRECT SOLAR RADIATION ON VARIOUS SLOPES FROM 0 TO 60 DEGREES NORTH LATITUDE

142, 74, 1972  
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**ABSTRACT**

*Direct beam solar radiation is presented in graphical and tabular form for hourly, daily, and yearly values for seven slopes on each of 16 aspects from the Equator to 60 degrees north in 10-degree increments. Theoretical equations necessary for the calculations are given. Solar altitude and azimuth during the day and year are also presented for the same latitudes.*

**Keywords:** *Solar radiation, slopes, aspects.*

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## INTRODUCTION

Solar energy is by far the most important climatic factor. There are many situations in which accessible information concerning solar intensity might be used. For example, it is a significant parameter in ecological problems dealing with silviculture, entomology, pathology, and fire control.

Optimum use of solar energy requires knowledge of the exact location of the sun and the magnitude of insolation at any time of the day and year. Tables and graphs have been prepared which give the sun's location (that is, altitude and azimuth) as a function of latitude, time of day, and year (Smithsonian Institution 1958, Hutchinson and Cotter 1955). More recently, computer programs have been written which give not only the sun's location but also direct solar radiation on a horizontal surface (Robertson and Russello 1968, Furnival et al. 1969). However, direct solar radiation on a horizontal surface may not be as useful as radiation on sloping surfaces or vertical walls. Such tables have been prepared by Frank and Lee (1966) and Fons et al. (1960). These tables present either daily solar radiation values or coefficients which have to be multiplied by direct solar radiation on a horizontal surface for specific aspects, slopes, and latitudes. Such tables are of limited use because of the range of latitudes and slopes presented and because additional calculations are required. Therefore, computer programs were modified and written to calculate direct solar radiation on selected slopes and aspects in 10-degree increments from the Equator to 60 degrees north. These results are presented in tabular form and as graphical plots of hourly and daily values.

## THEORY

Theoretical derivation of the necessary equations has been given by Byram and Jemison (1943), Fons et al. (1960), and Frank and Lee (1966), among others. These equations are presented here for completeness. A sample surface is located in the Northern Hemisphere as shown in figure 1. The sun is directly overhead at point  $p$  on meridian  $lq$  with a declination  $\delta$ . The sample surface is located at latitude  $\phi$ , point  $r$ , on meridian  $mq$  which has an hour angle  $h$  from the meridian  $lq$ . The surface  $cfgi$  has a slope  $\alpha$  from the horizontal  $jo$ , a deviation of  $\theta$  from the vertical  $ed$ , and an aspect  $\beta$  from the north  $no$ .

The sun's rays are striking the surface at  $r$  with an altitude angle  $Sok$ , called  $A$ , from the horizontal. The altitude  $A$  is given by:

$$\sin A = \sin \phi \sin \delta + \cos \phi \cos \delta \cos h;$$

and the azimuth  $AZ$  from the north, where  $AZ = Z + 90$  degrees, is given by:

$$\sin AZ = -\cos \delta \sin h / \cos A.$$

The solar intensity  $I$  on the surface  $cfgi$  is:

$$I = I_0 \sin A \sin \theta$$

where

$$\sin \theta = \sin A \cos \alpha - \cos A \sin \alpha \sin (Z - \beta).$$

$I_0$  is the radiation at the top of the atmosphere on a surface normal to the sun's rays and  $p$  is the atmospheric transmission coefficient.

A computer program, written by Furnival et al. (1969), calculated direct solar radiation at the top of the atmosphere on a surface parallel to the earth's surface. This program was modified to calculate direct solar radiation at the earth's surface on any slope and aspect, at latitudes from 0 to 60 degrees north, with any atmospheric transmission coefficient.

## RESULTS AND DISCUSSION

Hourly solar radiation was computed for: slopes in 15-degree increments ranging from level to a vertical wall; 16 aspects, in 22-1/2-degree increments; 20 selected days of the year; latitudes, in 10-degree increments, from 0 to 60 degrees north; and atmospheric transmission coefficient of 0.9. The possible combinations are detailed in table 1. Other options may have been desirable but were too costly. At latitudes greater than 60 degrees, where the sun does not set on certain days, the computations become more difficult and so were omitted.

The atmospheric coefficient of 0.9 was selected because it was representative of conditions on the top of a mountain, about 1,500 m., on a clear day. Other values would be useful for some areas where atmospheric pollution is severe. List (Smithsonian Institution 1958) presents seasonal totals of direct solar radiation with different atmospheric coefficients at many latitudes. These values may be useful for comparison.

The hourly computations for the selected days are displayed in four ways as: (1) isograms of radiation drawn on graphs of time versus slope for specific days, aspects, and latitudes, (2) daily totals in tabular form for specific days, aspects, and latitudes, (3) isograms of daily totals versus days for specific latitudes, and (4) annual totals in tabular form for specific slopes, aspects, and latitudes. The details of display are discussed in the following section.

The computed values apply only to surfaces on level terrain where sunrise and sunset are not restricted by topographic features. Many applications of the radiation values are in city or mountainous areas which have limited day length. Other computer programs can be utilized for these special applications.<sup>1/</sup> Knowledge of the solar altitude and azimuth as a function of the time of day and day of year is required to compute solar radiation for these areas. List (Smithsonian Institution 1958) presents, in convenient graphical form, solar azimuths and elevations for the same days and latitudes as listed in table 1. For completeness, the graphs are duplicated here (figs. 51-57).<sup>2/</sup>

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<sup>1/</sup> Ross Lake Solar Program, Forest Meteorology, College of Forest Resources, University of Washington.

<sup>2/</sup> Courtesy of the Smithsonian Institution Press, Washington, D.C.



## EXPLANATION OF FIGURES AND TABLES

Isograms of direct solar radiation (hourly values drawn for every 10 and labeled for every 20 cal. cm.<sup>-2</sup>) were drawn on graphs of time (hours) versus slope (degrees) for each of the nine aspects and each of the 8 days at the seven latitudes. For convenience, all of the graphs for a specific day and latitude have been reduced and displayed together (figs. 2-36). Some subfigures are labeled double because the east and west aspects are mirror images with respect to solar radiation. The degree of slope is denoted across the bottom of each graph. The reader should note that:

- (1) the left axis radiation values (zero slope) for each graph for a given day are the same for the same hours of each day,
- (2) the south-facing walls (right axis of subfigure south) are in sunlight when the north-facing walls (right axis of subfigure north) are not,
- (3) the east-facing slopes are in sunlight while the comparable west-facing slopes are not,
- (4) the hours of daylight decrease from summer (fig. 21) to winter (fig. 17), and
- (5) the degree of slope receiving the most radiation increases from summer to winter as the sun's altitude decreases.

The second method of presentation of the radiation data is in tabular form. The hourly values were accumulated to form daily totals. These are presented in tables 2-8 as a function of degree of slope and aspect for each of the 20 days and for each latitude. (See table 1 for days of equal value.)

The daily totals of solar radiation for selected north-, east-, and south-facing slopes were plotted versus day of the year (figs. 37-50). There are two graphs for each latitude, one containing the isograms for level, north 30-, north 60-, north 90-, and east 30-degree slopes, and the other containing isograms for east 60-, east 90-, south 30-, south 60-, and south 90-degree slopes. These graphs can be used for quick comparison of various slopes and aspects; it should be noted that the values for the east and west slopes are equal. The latter half of the year can be assumed to be symmetrical to the first half.

Annual values of solar radiation for each slope and aspect are given in tables 9-15. Small errors exist in these totals because it was assumed that the period from December 22 to June 22 was identical to the period from June 22 to December 22. This error is small compared with variations in atmospheric transmission coefficients and in determining the slope and aspect of a particular surface.

Solar altitude and azimuth for the seven latitudes are given in figures 51-57. The user should refer to table 1 for the approximate date of the various declinations. For example, the declination of -5 degrees occurs on March 8 and October 6. Figure 51 shows the solar azimuth at 10:00 a.m. on either of the above dates to be 100 degrees and the elevation to be 60 degrees above the horizon. Intermediate latitudes can be linearly interpolated.

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Table 1.--Input data from which hourly values, daily and yearly totals of direct solar radiation were computed using the atmospheric transmission coefficient of 0.9

Approximate date	Declination	Latitude	Slope	Aspect
-----Degrees-----				
December 22	-23°27'	0	0	N
Jan. 21-Nov. 22	-20°	10	15	NNE-NNW
Feb. 9-Nov. 3	-15°	20	30	NE-NW
Feb. 23-Oct. 20	-10°	30	45	ENE-WNW
Mar. 8-Oct. 6	-5°	40	60	E-W
Mar. 21-Sept. 23	0°	50	75	ESE-WSW
Apr. 3-Sept. 10	+5°	60	90	SE-SW
Apr. 16-Aug. 28	+10°	--	--	SSE-SSW
May 1-Aug. 12	+15°	--	--	S
May 21-July 24	+20°	--	--	--
June 22	+23°27'	--	--	--

Table 2.--Daily values of direct solar radiation computed for selected slopes, aspects, and days  
at 0 degrees north latitude  
(Cal.  $\text{cm}^{-2} \text{ day}^{-1}$ )

LATITUDE SLOPE (DEGREES)	0 DEGREES NORTH, DEC. 22 ASPECT								
	N	NNE	NE	ENE	E	ESE	SE	SSE	S
0	714	714	714	714	714	714	714	714	714
15	574	587	614	652	695	736	770	795	804
30	406	429	491	567	646	716	779	823	840
45	216	263	361	471	576	662	735	794	818
60	44	111	242	372	490	581	650	711	741
75	0	15	147	280	397	479	531	580	613
90	0	0	81	199	302	368	395	409	443

LATITUDE SLOPE (DEGREES)	0 DEGREES NORTH, FEB. 23 ASPECT								
	N	NNE	NE	ENE	E	ESE	SE	SSE	S
0	766	766	766	766	766	766	766	766	766
15	687	692	707	726	746	764	778	788	792
30	562	578	612	655	694	723	744	757	764
45	402	433	496	565	620	651	668	677	685
60	217	275	374	464	529	557	559	551	558
75	35	134	258	361	429	450	433	394	394
90	0	46	163	263	327	341	307	234	202

LATITUDE SLOPE (DEGREES)	0 DEGREES NORTH, JAN. 21 ASPECT								
	N	NNE	NE	ENE	E	ESE	SE	SSE	S
0	733	733	733	733	733	733	733	733	733
15	609	619	644	677	715	750	779	800	808
30	449	470	527	595	664	724	776	813	828
45	262	307	400	500	592	664	722	770	791
60	81	153	276	399	505	579	630	674	700
75	0	40	176	302	409	475	508	533	561
90	0	3	101	216	311	363	373	359	385

LATITUDE SLOPE (DEGREES)	0 DEGREES NORTH, MAR. 8 ASPECT								
	N	NNE	NE	ENE	E	ESE	SE	SSE	S
0	771	771	771	771	771	771	771	771	771
15	717	719	729	740	751	760	766	770	772
30	614	624	646	676	699	712	716	718	721
45	469	491	538	590	624	635	630	621	620
60	294	338	417	490	533	539	516	484	478
75	102	188	299	385	432	432	391	326	302
90	0	81	195	284	330	325	271	179	107

LATITUDE SLOPE (DEGREES)	0 DEGREES NORTH, FEB. 9 ASPECT								
	N	NNE	NE	ENE	E	ESE	SE	SSE	S
0	754	754	754	754	754	754	754	754	754
15	652	660	680	706	735	761	782	798	804
30	508	527	574	629	683	727	764	788	799
45	335	373	452	536	609	661	698	724	740
60	147	214	328	435	520	569	595	614	631
75	0	85	217	334	421	463	470	461	478
90	0	20	134	241	321	353	341	291	293

LATITUDE SLOPE (DEGREES)	0 DEGREES NORTH, MAR. 21 ASPECT								
	N	NNE	NE	ENE	E	ESE	SE	SSE	S
0	769	769	769	769	769	769	769	769	769
15	741	741	744	748	749	749	746	744	744
30	663	667	676	691	697	693	680	672	668
45	539	549	575	610	622	612	584	556	547
60	379	404	461	512	531	514	467	412	389
75	193	250	339	407	431	409	344	257	204
90	0	123	230	303	329	305	235	128	5

Table 2.--Daily values of direct solar radiation computed for selected slopes, aspects, and days  
at 0 degrees north latitude--*CONTINUED*  
(Cal. cm<sup>-2</sup> day<sup>-1</sup>)

LATITUDE SLOPE (DEGREES)	0 DEGREES NORTH, APR. 3 ASPECT								
	N	NNE	NE	ENE	E	ESE	SE	SSE	S
0	759	759	759	759	759	759	759	759	759
15	758	756	753	748	740	730	720	711	709
30	704	703	701	699	689	668	640	620	610
45	603	604	615	623	615	583	534	490	470
60	461	469	503	528	525	485	416	340	299
75	287	314	380	423	426	382	299	192	110
90	94	171	263	318	325	282	196	84	0

LATITUDE SLOPE (DEGREES)	0 DEGREES NORTH, MAY 21 ASPECT								
	N	NNE	NE	ENE	E	ESE	SE	SSE	S
0	692	692	692	692	692	692	692	692	692
15	763	756	735	708	674	639	607	584	574
30	782	768	733	683	627	561	497	443	423
45	747	728	682	627	559	471	376	289	246
60	662	638	596	547	476	376	259	143	75
75	532	505	480	449	386	285	165	37	0
90	365	348	353	343	294	203	94	2	0

LATITUDE SLOPE (DEGREES)	0 DEGREES NORTH, APR. 16 ASPECT								
	N	NNE	NE	ENE	E	ESE	SE	SSE	S
0	744	744	744	744	744	744	744	744	744
15	767	763	754	742	725	706	689	675	670
30	737	730	719	701	675	638	598	566	551
45	658	651	644	630	602	551	486	427	397
60	533	527	538	539	514	453	367	274	219
75	372	375	416	435	417	353	255	136	39
90	186	220	294	329	318	258	162	48	0

LATITUDE SLOPE (DEGREES)	0 DEGREES NORTH, JUN. 22 ASPECT								
	N	NNE	NE	ENE	E	ESE	SE	SSE	S
0	668	668	668	668	668	668	668	668	668
15	753	745	722	690	651	611	575	549	538
30	786	771	729	678	605	531	468	402	380
45	766	744	688	620	539	441	338	247	203
60	694	666	609	544	459	348	227	104	41
75	574	543	497	449	372	262	138	14	0
90	415	383	370	345	283	186	76	0	0

LATITUDE SLOPE (DEGREES)	0 DEGREES NORTH, MAY 1 ASPECT								
	N	NNE	NE	ENE	E	ESE	SE	SSE	S
0	722	722	722	722	722	722	722	722	722
15	769	763	748	728	703	676	651	632	625
30	764	753	730	696	654	603	550	506	488
45	706	692	667	632	583	514	433	358	323
60	601	585	568	544	498	417	315	207	143
75	455	439	449	443	403	321	208	83	0
90	277	277	325	337	307	231	129	20	0



Table 3.--Daily values of direct solar radiation computed for selected slopes, aspects, and days at 10 degrees north latitude

(Cal. cm<sup>-2</sup> day<sup>-1</sup>)

LATITUDE 10 DEGREES NORTH, DEC. 22									
SLOPE (DEGREES)	ASPECT								
	N	NNE	NE	ENE	E	ESE	SE	SSE	S
	NNW	NW	WNW	W	WSW	SW	SSW		
0	609	609	609	609	609	609	609	609	609
15	456	466	496	540	591	642	684	712	723
30	273	304	370	457	549	637	713	767	787
45	94	147	253	372	491	598	694	770	798
60	0	31	154	290	420	535	635	720	754
75	0	0	89	217	342	450	537	621	659
90	0	0	48	153	262	352	415	479	519

LATITUDE 10 DEGREES NORTH, FEB. 23									
SLOPE (DEGREES)	ASPECT								
	N	NNE	NE	ENE	E	ESE	SE	SSE	S
	NNW	NW	WNW	W	WSW	SW	SSW		
0	712	712	712	712	712	712	712	712	712
15	603	612	633	652	694	725	749	765	772
30	455	474	525	586	647	699	739	767	779
45	279	318	405	496	579	641	687	718	733
60	91	170	288	402	497	558	596	621	637
75	0	64	154	311	406	459	479	483	498
90	0	22	122	228	312	352	352	322	325

LATITUDE 10 DEGREES NORTH, JAN. 21									
SLOPE (DEGREES)	ASPECT								
	N	NNE	NE	ENE	E	ESE	SE	SSE	S
	NNW	NW	WNW	W	WSW	SW	SSW		
0	641	641	641	641	641	641	641	641	641
15	497	508	536	577	623	669	707	733	743
30	322	350	412	493	580	660	727	775	794
45	138	189	292	406	519	616	700	765	790
60	0	61	190	321	445	547	632	702	733
75	0	5	114	243	363	458	529	592	627
90	0	0	66	174	278	357	404	441	477

LATITUDE 10 DEGREES NORTH, MAR. 8									
SLOPE (DEGREES)	ASPECT								
	N	NNE	NE	ENE	E	ESE	SE	SSE	S
	NNW	NW	WNW	W	WSW	SW	SSW		
0	737	737	737	737	737	737	737	737	737
15	650	656	673	695	718	740	757	768	773
30	519	535	574	623	670	706	732	749	756
45	354	387	458	535	600	642	667	681	688
60	167	232	340	439	514	554	568	566	573
75	0	109	235	343	420	451	448	422	419
90	0	44	154	252	322	343	322	263	237

LATITUDE 10 DEGREES NORTH, FEB. 9									
SLOPE (DEGREES)	ASPECT								
	N	NNE	NE	ENE	E	ESE	SE	SSE	S
	NNW	NW	WNW	W	WSW	SW	SSW		
0	591	581	681	681	681	681	681	681	681
15	553	564	589	624	663	702	733	754	762
30	392	415	472	544	618	684	738	776	792
45	205	256	349	454	553	633	698	746	767
60	33	114	241	364	475	557	617	665	690
75	0	30	114	279	388	462	507	539	566
90	0	7	93	203	298	358	379	380	404

LATITUDE 10 DEGREES NORTH, MAR. 21									
SLOPE (DEGREES)	ASPECT								
	N	NNE	NE	ENE	E	ESE	SE	SSE	S
	NNW	NW	WNW	W	WSW	SW	SSW		
0	756	756	756	756	756	756	756	756	756
15	694	697	708	722	737	749	758	763	766
30	585	595	620	656	687	707	716	722	724
45	436	456	510	570	614	635	638	633	633
60	277	302	391	473	526	543	532	507	498
75	61	162	279	373	429	438	409	356	330
90	0	74	186	277	329	330	295	203	139

Table 3.--Daily values of direct solar radiation computed for selected slopes, aspects, and days  
at 10 degrees north latitude --CONTINUED

(Cal. cm<sup>-2</sup> day<sup>-1</sup>)

LATITUDE 10 DEGREES NORTH, APR. 3									
SLOPE (DEGREES)	ASPECT								
	N	NNE	NE	ENE	E	ESE	SE	SSE	S
	NNW	NW	WNW	W	WSW	SW	SSW		
0	767	767	767	767	767	767	767	767	767
15	731	732	736	742	748	751	751	750	751
30	645	648	662	682	696	699	692	688	684
45	515	524	559	599	622	622	603	579	570
60	350	372	439	501	532	525	489	443	417
75	161	221	323	398	432	419	365	289	238
90	10	111	220	298	330	313	247	147	49

LATITUDE 10 DEGREES NORTH, MAY 21									
SLOPE (DEGREES)	ASPECT								
	N	NNE	NE	ENE	E	ESE	SE	SSE	S
	NNW	NW	WNW	W	WSW	SW	SSW		
0	759	759	759	759	759	759	759	759	759
15	708	793	779	759	737	713	690	672	667
30	783	774	750	719	683	638	590	551	531
45	715	701	674	647	607	545	471	403	370
60	598	581	566	552	515	443	347	246	190
75	440	422	440	445	414	339	230	106	27
90	252	252	314	337	313	241	136	19	0

LATITUDE 10 DEGREES NORTH, APR. 16									
SLOPE (DEGREES)	ASPECT								
	N	NNE	NE	ENE	E	ESE	SE	SSE	S
	NNW	NW	WNW	W	WSW	SW	SSW		
0	771	771	771	771	771	771	771	771	771
15	760	759	756	755	751	745	738	731	730
30	697	694	698	701	698	686	654	649	639
45	586	586	603	620	623	602	563	525	505
60	435	441	485	523	531	503	444	378	342
75	255	281	361	418	431	397	322	227	156
90	57	152	252	314	328	292	212	99	0

LATITUDE 10 DEGREES NORTH, JUN. 22									
SLOPE (DEGREES)	ASPECT								
	N	NNE	NE	ENE	E	ESE	SE	SSE	S
	NNW	NW	WNW	W	WSW	SW	SSW		
0	747	747	747	747	747	747	747	747	747
15	802	796	778	752	725	695	668	647	641
30	802	790	758	718	671	617	560	515	494
45	748	731	692	650	595	522	438	361	325
60	643	622	588	557	504	419	313	203	147
75	493	470	460	450	404	317	199	70	4
90	311	289	333	341	304	222	113	2	0

LATITUDE 10 DEGREES NORTH, MAY 1									
SLOPE (DEGREES)	ASPECT								
	N	NNE	NE	ENE	E	ESE	SE	SSE	S
	NNW	NW	WNW	W	WSW	SW	SSW		
0	769	769	769	769	769	769	769	769	769
15	793	780	771	761	748	733	718	705	702
30	743	737	727	713	694	665	630	603	588
45	653	645	642	636	618	577	519	467	439
60	519	511	523	540	526	476	397	314	264
75	349	343	402	434	425	370	278	164	85
90	155	198	283	328	323	268	173	55	0

Table 4.--Daily values of direct solar radiation computed for selected slopes, aspects, and days  
at 20 degrees north latitude  
(Cal. cm<sup>-2</sup> day<sup>-1</sup>)

SLOPE (DEGREES)	LATITUDE 20 DEGREES NORTH, DEC. 22 ASPECT								
	N	NNE	NE	ENE	E	ESE	SE	SSE	S
0	492	492	492	492	492	492	492	492	492
15	327	339	374	423	478	533	581	613	624
30	150	182	255	348	447	545	630	692	714
45	5	51	156	278	403	528	639	724	755
60	0	0	87	215	351	484	607	706	744
75	0	0	49	162	293	420	535	641	683
90	0	0	28	118	230	338	435	531	575

SLOPE (DEGREES)	LATITUDE 20 DEGREES NORTH, FEB. 23 ASPECT								
	N	NNE	NE	ENE	E	ESE	SE	SSE	S
0	634	634	634	634	634	634	634	634	634
15	501	511	537	574	617	658	693	715	724
30	336	360	420	496	576	649	706	748	764
45	150	205	305	415	519	608	679	731	752
60	0	82	208	335	450	540	610	664	689
75	0	25	136	261	372	456	512	551	579
90	0	10	88	193	289	357	392	407	430

SLOPE (DEGREES)	LATITUDE 20 DEGREES NORTH, JAN. 21 ASPECT								
	N	NNE	NE	ENE	E	ESE	SE	SSE	S
0	533	533	533	533	533	533	533	533	533
15	374	385	417	464	516	569	614	645	656
30	194	226	298	387	481	575	654	713	734
45	29	85	190	312	433	550	653	732	761
60	0	8	115	244	376	499	611	702	737
75	0	0	65	185	311	429	531	623	663
90	0	0	37	134	243	342	422	502	544

SLOPE (DEGREES)	LATITUDE 20 DEGREES NORTH, MAR. 8 ASPECT								
	N	NNE	NE	ENE	E	ESE	SE	SSE	S
0	677	677	677	677	677	677	677	677	677
15	562	571	593	625	660	694	722	739	746
30	408	429	483	550	618	677	721	753	764
45	229	274	365	465	557	628	681	716	730
60	40	136	262	380	483	554	601	630	647
75	0	55	178	299	399	462	493	506	519
90	0	25	118	223	311	360	369	354	356

SLOPE (DEGREES)	LATITUDE 20 DEGREES NORTH, FEB. 9 ASPECT								
	N	NNE	NE	ENE	E	ESE	SE	SSE	S
0	587	587	587	587	587	587	587	587	587
15	441	451	479	520	568	616	657	684	694
30	265	294	359	442	529	613	682	734	753
45	84	143	247	353	475	579	667	734	761
60	0	39	158	288	411	518	610	685	716
75	0	6	98	220	338	440	520	588	624
90	0	0	59	159	262	346	405	451	488

SLOPE (DEGREES)	LATITUDE 20 DEGREES NORTH, MAR. 21 ASPECT								
	N	NNE	NE	ENE	E	ESE	SE	SSE	S
0	716	716	716	716	716	716	716	716	716
15	623	628	647	672	699	724	743	756	761
30	487	502	545	600	653	697	726	747	754
45	317	350	429	514	588	640	672	688	695
60	127	200	315	423	508	558	581	585	589
75	0	95	224	334	419	459	466	449	443
90	0	47	151	250	325	353	340	294	267

Table 4.--Daily values of direct solar radiation computed for selected slopes, aspects, and days  
at 20 degrees north latitude --CONTINUED  
(Cal. cm<sup>-2</sup> day<sup>-1</sup>)

LATITUDE 20 DEGREES NORTH, APR. 3									
SLOPE (DEGREES)	ASPECT								
	N	NNE	NE	ENE	E	ESE	SE	SSE	S
	NNW	NW	WNW	W	WSW	SW	SSW		
0	748	748	748	748	748	748	748	748	748
15	679	682	693	711	729	745	757	764	767
30	562	571	600	643	681	708	722	731	734
45	408	426	488	557	611	641	653	652	650
60	226	270	371	462	526	553	552	534	522
75	28	143	266	366	431	449	431	387	359
90	4	75	184	275	333	340	305	233	175

LATITUDE 20 DEGREES NORTH, MAY 21									
SLOPE (DEGREES)	ASPECT								
	N	NNE	NE	ENE	E	ESE	SE	SSE	S
	NNW	NW	WNW	W	WSW	SW	SSW		
0	800	800	800	800	800	800	800	800	800
15	804	802	795	785	774	762	750	743	741
30	754	749	738	729	715	693	665	643	631
45	652	646	639	642	634	602	555	509	483
60	506	498	517	540	536	497	428	353	311
75	326	321	386	431	431	385	300	198	132
90	123	181	273	323	324	276	195	67	0

LATITUDE 20 DEGREES NORTH, APR. 16									
SLOPE (DEGREES)	ASPECT								
	N	NNE	NE	ENE	E	ESE	SE	SSE	S
	NNW	NW	WNW	W	WSW	SW	SSW		
0	772	772	772	772	772	772	772	772	772
15	726	728	732	741	751	758	762	764	766
30	631	633	651	677	699	710	711	709	707
45	492	500	541	591	625	636	627	610	600
60	320	340	420	493	536	541	517	479	453
75	126	195	307	392	437	434	392	327	282
90	21	104	213	295	335	324	267	174	97

LATITUDE 20 DEGREES NORTH, JUN. 22									
SLOPE (DEGREES)	ASPECT								
	N	NNE	NE	ENE	E	ESE	SE	SSE	S
	NNW	NW	WNW	W	WSW	SW	SSW		
0	800	800	800	800	800	800	800	800	800
15	821	818	807	792	774	756	739	729	725
30	786	779	759	740	714	682	645	616	601
45	698	688	668	656	631	586	527	472	444
60	562	549	544	531	532	478	397	313	264
75	387	373	413	440	426	366	271	157	90
90	186	209	291	330	319	259	159	37	0

LATITUDE 20 DEGREES NORTH, MAY 1									
SLOPE (DEGREES)	ASPECT								
	N	NNE	NE	ENE	E	ESE	SE	SSE	S
	NNW	NW	WNW	W	WSW	SW	SSW		
0	790	790	790	790	790	790	790	790	790
15	769	768	767	766	766	764	759	757	757
30	695	694	698	705	711	705	692	680	672
45	574	573	593	619	633	622	595	561	542
60	414	416	469	519	539	522	476	418	385
75	226	253	348	414	436	412	347	261	201
90	76	140	242	311	332	302	226	119	34

Table 5.--Daily values of direct solar radiation computed for selected slopes, aspects, and days  
at 30 degrees north latitude  
(Cal. cm<sup>-2</sup> day<sup>-1</sup>)

SLOPE (DEGREES)	LATITUDE 30 DEGREES NORTH, DEC. 22 ASPECT								
	N	NNE	NE	ENE	E	ESE	SE	SSE	S
0	362	362	362	362	362	362	362	362	362
15	198	212	247	297	355	411	459	492	504
30	41	73	146	236	338	436	525	589	612
45	0	0	77	188	314	441	558	645	677
60	0	0	41	146	280	418	552	658	697
75	0	0	24	116	241	378	509	625	669
90	0	0	16	87	197	316	437	550	596

SLOPE (DEGREES)	LATITUDE 30 DEGREES NORTH, FEB. 23 ASPECT								
	N	NNE	NE	ENE	E	ESE	SE	SSE	S
0	536	536	536	536	536	536	536	536	536
15	386	396	425	470	519	569	612	640	650
30	209	239	309	396	486	574	645	701	720
45	34	100	206	326	442	552	644	713	741
60	0	26	135	262	388	502	599	677	711
75	0	7	87	205	326	435	524	595	632
90	0	2	57	154	258	349	418	474	511

SLOPE (DEGREES)	LATITUDE 30 DEGREES NORTH, JAN. 21 ASPECT								
	N	NNE	NE	ENE	E	ESE	SE	SSE	S
0	410	410	410	410	410	410	410	410	410
15	244	259	295	345	402	456	504	537	549
30	76	111	187	279	381	479	565	628	650
45	0	13	107	225	352	478	590	675	707
60	0	0	63	180	313	448	576	677	716
75	0	0	39	140	269	401	524	632	675
90	0	0	25	107	218	333	442	544	589

SLOPE (DEGREES)	LATITUDE 30 DEGREES NORTH, MAR. 8 ASPECT								
	N	NNE	NE	ENE	E	ESE	SE	SSE	S
0	594	594	594	594	594	594	594	594	594
15	455	466	494	534	579	623	660	683	692
30	287	313	377	460	544	622	682	727	743
45	100	164	272	387	496	593	669	722	743
60	0	64	187	318	437	535	612	667	693
75	0	27	130	253	368	460	526	569	595
90	0	14	90	193	292	368	413	437	457

SLOPE (DEGREES)	LATITUDE 30 DEGREES NORTH, FEB. 9 ASPECT								
	N	NNE	NE	ENE	E	ESE	SE	SSE	S
0	478	478	478	478	478	478	478	478	478
15	317	328	363	411	465	517	564	595	606
30	141	175	249	341	439	532	611	672	693
45	0	52	158	277	402	521	624	702	732
60	0	6	97	222	354	481	594	685	722
75	0	0	63	174	301	423	531	621	662
90	0	0	39	132	242	346	434	515	558

SLOPE (DEGREES)	LATITUDE 30 DEGREES NORTH, MAR. 21 ASPECT								
	N	NNE	NE	ENE	E	ESE	SE	SSE	S
0	651	651	651	651	651	651	651	651	651
15	530	538	563	598	636	673	702	721	728
30	373	393	452	524	598	663	710	744	756
45	190	238	338	446	545	624	681	718	731
60	0	115	245	370	478	558	612	642	657
75	0	56	174	297	402	473	513	530	538
90	0	31	123	228	318	375	394	385	383



Table 5.--Daily values of direct solar radiation computed for selected slopes, aspects, and days  
at 30 degrees north latitude--CONTINUED  
(Cal. cm<sup>-2</sup> day<sup>-1</sup>)

LATITUDE 30 DEGREES NORTH, APR. 3									
SLOPE (DEGREES)	ASPECT								
	N	NNE	NE	ENE	E	ESE	SE	SSE	S
	NNW	NW	WNW	W	WSW	SW	SSW		
0	703	703	703	703	703	703	703	703	703
15	602	608	627	655	686	714	735	750	756
30	461	475	521	583	643	692	727	749	757
45	287	318	405	493	582	642	681	701	707
60	95	174	300	414	508	566	598	606	608
75	5	91	217	333	423	473	487	479	463
90	1	53	152	255	332	368	361	327	297

LATITUDE 30 DEGREES NORTH, MAY 21									
SLOPE (DEGREES)	ASPECT								
	N	NNE	NE	ENE	E	ESE	SE	SSE	S
	NNW	NW	WNW	W	WSW	SW	SSW		
0	816	816	816	816	816	816	816	816	816
15	783	789	790	792	793	793	792	791	789
30	709	709	712	726	736	736	729	716	711
45	579	579	599	635	658	655	634	602	585
60	411	411	471	535	565	554	516	460	429
75	214	244	354	430	461	441	384	301	249
90	79	147	254	327	353	326	252	144	76

LATITUDE 30 DEGREES NORTH, APR. 16									
SLOPE (DEGREES)	ASPECT								
	N	NNE	NE	ENE	E	ESE	SE	SSE	S
	NNW	NW	WNW	W	WSW	SW	SSW		
0	746	746	746	746	746	746	746	746	746
15	667	671	683	702	725	745	759	770	774
30	542	550	583	631	677	711	733	746	750
45	381	397	465	544	609	650	671	675	674
60	193	238	350	452	527	565	575	565	553
75	32	130	256	360	435	463	456	422	398
90	11	75	181	273	338	353	328	267	219

LATITUDE 30 DEGREES NORTH, JUN. 22									
SLOPE (DEGREES)	ASPECT								
	N	NNE	NE	ENE	E	ESE	SE	SSE	S
	NNW	NW	WNW	W	WSW	SW	SSW		
0	833	833	833	833	833	833	833	833	833
15	825	823	819	816	810	804	796	790	786
30	760	757	753	755	751	739	722	700	692
45	644	640	643	664	671	652	617	573	551
60	483	478	513	560	574	547	492	422	387
75	290	292	389	452	468	432	357	258	206
90	119	179	280	345	358	316	226	108	42

LATITUDE 30 DEGREES NORTH, MAY 1									
SLOPE (DEGREES)	ASPECT								
	N	NNE	NE	ENE	E	ESE	SE	SSE	S
	NNW	NW	WNW	W	WSW	SW	SSW		
0	783	783	783	783	783	783	783	783	783
15	727	730	736	746	758	769	777	783	786
30	622	626	644	674	704	723	732	734	735
45	474	480	525	584	630	650	653	642	633
60	294	310	403	486	540	556	545	515	492
75	94	176	294	386	441	447	419	364	325
90	31	103	208	291	338	334	288	207	143

Table 6.--Daily values of direct solar radiation computed for selected slopes, aspects, and days  
at 40 degrees north latitude  
(Cal. cm<sup>-2</sup> day<sup>-1</sup>)

LATITUDE 40 DEGREES NORTH, DEC. 22 ASPECT										LATITUDE 40 DEGREES NORTH, FEB. 23 ASPECT									
SLOPE (DEGREES)	N	NNE NNW	NE NW	ENE WNW	E W	ESE WSW	SE SW	SSE SSW	S	SLOPE (DEGREES)	N	NNE NNW	NE NW	ENE WNW	E W	ESE WSW	SE SW	SSE SSW	S
0	229	229	229	229	229	229	229	229	229	0	423	423	423	423	423	423	423	423	423
15	82	96	128	173	223	275	321	351	362	15	261	273	309	358	413	466	513	545	556
30	0	2	54	127	214	306	390	449	470	30	86	124	202	295	395	488	570	629	651
45	0	0	21	98	203	320	433	517	546	45	0	30	126	244	369	489	593	671	702
60	0	0	9	78	188	316	447	549	584	60	0	6	85	203	334	462	576	668	705
75	0	0	5	63	163	295	430	543	583	75	0	2	60	163	290	416	528	618	660
90	0	0	3	46	138	253	386	501	542	90	0	0	41	130	239	348	444	527	570
LATITUDE 40 DEGREES NORTH, JAN. 21 ASPECT										LATITUDE 40 DEGREES NORTH, MAR. 8 ASPECT									
SLOPE (DEGREES)	N	NNE NNW	NE NW	ENE WNW	E W	ESE WSW	SE SW	SSE SSW	S	SLOPE (DEGREES)	N	NNE NNW	NE NW	ENE WNW	E W	ESE WSW	SE SW	SSE SSW	S
0	278	278	278	278	278	278	278	278	278	0	491	491	491	491	491	491	491	491	491
15	123	136	171	218	272	327	373	405	416	15	336	348	379	426	478	529	573	602	612
30	0	21	87	170	262	357	444	504	526	30	160	192	268	360	454	544	618	673	692
45	0	0	42	135	249	370	485	569	600	45	0	71	180	300	421	534	628	697	724
60	0	0	24	110	230	361	492	595	633	60	0	24	123	248	377	497	596	674	707
75	0	0	15	89	200	335	468	581	623	75	0	11	88	202	326	440	535	605	642
90	0	0	11	68	169	287	414	527	570	90	0	6	61	159	266	363	439	499	533
LATITUDE 40 DEGREES NORTH, FEB. 9 ASPECT										LATITUDE 40 DEGREES NORTH, MAR. 21 ASPECT									
SLOPE (DEGREES)	N	NNE NNW	NE NW	ENE WNW	E W	ESE WSW	SE SW	SSE SSW	S	SLOPE (DEGREES)	N	NNE NNW	NE NW	ENE WNW	E W	ESE WSW	SE SW	SSE SSW	S
0	353	353	353	353	353	353	353	353	353	0	564	564	564	564	564	564	564	564	564
15	189	204	240	290	347	402	449	482	493	15	420	431	461	503	551	598	636	659	669
30	31	68	144	235	335	430	517	578	600	30	248	276	346	435	523	606	668	713	729
45	0	4	84	194	317	440	551	634	666	45	59	134	248	372	485	587	666	719	738
60	0	0	53	161	290	423	548	647	686	60	0	60	181	313	436	541	621	675	698
75	0	0	37	132	254	387	512	616	659	75	0	34	134	258	376	474	545	589	610
90	0	0	27	104	213	329	443	543	588	90	0	22	99	204	306	388	439	466	480

Table 6.--Daily values of direct solar radiation computed for selected slopes, aspects, and days  
at 40 degrees north latitude--*CONTINUED*  
(Cal. cm<sup>-2</sup> day<sup>-1</sup>)

LATITUDE 40 DEGREES NORTH, APR. 3									
SLOPE (DEGREES)	ASPECT								
	N	NNE	NE	ENE	E	ESE	SE	SSE	S
	NNW	NW	NNW	W	WSW	SW	SSW		
0	633	633	633	633	633	633	633	633	633
15	506	514	539	577	618	657	688	709	718
30	344	363	425	504	584	654	706	740	753
45	158	207	318	433	537	623	686	724	737
60	10	104	234	365	478	565	625	658	671
75	2	60	176	300	408	487	535	555	559
90	0	38	130	235	329	392	419	416	409

LATITUDE 40 DEGREES NORTH, MAY 21									
SLOPE (DEGREES)	ASPECT								
	N	NNE	NE	ENE	E	ESE	SE	SSE	S
	NNW	NW	NNW	W	WSW	SW	SSW		
0	811	811	811	811	811	811	811	811	811
15	753	755	762	775	790	802	811	815	814
30	643	648	665	702	736	760	772	769	768
45	489	496	542	614	668	693	697	683	673
60	302	312	423	520	582	602	591	557	532
75	122	193	324	423	485	494	463	403	371
90	70	130	242	330	380	376	326	240	190

LATITUDE 40 DEGREES NORTH, APR. 16									
SLOPE (DEGREES)	ASPECT								
	N	NNE	NE	ENE	E	ESE	SE	SSE	S
	NNW	NW	NNW	W	WSW	SW	SSW		
0	694	694	694	694	694	694	694	694	694
15	584	591	610	639	674	705	731	749	756
30	435	448	496	565	632	689	731	756	766
45	256	284	379	482	576	645	692	717	724
60	60	153	284	405	506	575	616	631	633
75	14	90	210	330	426	486	511	511	499
90	6	57	154	256	338	382	388	363	337

LATITUDE 40 DEGREES NORTH, JUN. 22									
SLOPE (DEGREES)	ASPECT								
	N	NNE	NE	ENE	E	ESE	SE	SSE	S
	NNW	NW	NNW	W	WSW	SW	SSW		
0	843	843	843	843	843	843	843	843	843
15	802	803	805	811	819	825	828	828	827
30	705	707	715	739	762	774	775	765	761
45	561	564	589	645	685	697	688	664	650
60	378	382	462	546	594	599	573	526	498
75	175	231	353	444	491	484	439	365	326
90	98	154	264	343	382	362	299	199	147

LATITUDE 40 DEGREES NORTH, MAY 1									
SLOPE (DEGREES)	ASPECT								
	N	NNE	NE	ENE	E	ESE	SE	SSE	S
	NNW	NW	NNW	W	WSW	SW	SSW		
0	753	753	753	753	753	753	753	753	753
15	668	672	687	708	732	755	774	785	787
30	537	546	581	634	688	727	755	766	771
45	370	383	460	551	626	673	699	705	703
60	177	224	353	463	549	594	609	599	586
75	57	139	267	380	460	496	491	462	437
90	32	93	197	297	364	385	360	305	263

Table 7.--Daily values of direct solar radiation computed for selected slopes, aspects, and days  
at 50 degrees north latitude  
(Cal. cm<sup>-2</sup> day<sup>-1</sup>)

SLOPE (DEGREES)	LATITUDE 50 DEGREES NORTH, DEC. 22 ASPECT								
	N	NNE	NE	ENE	E	ESE	SE	SSE	S
	NNW	NW	WNW	W	WSW	SW	SSW		
0	105	105	105	105	105	105	105	105	105
15	3	12	34	67	104	145	179	203	211
30	0	0	5	44	105	175	241	287	303
45	0	0	1	35	106	195	286	351	373
60	0	0	0	30	102	204	311	391	419
75	0	0	0	25	95	200	316	404	436
90	0	0	0	19	84	181	299	390	423

SLOPE (DEGREES)	LATITUDE 50 DEGREES NORTH, FEB. 23 ASPECT								
	N	NNE	NE	ENE	E	ESE	SE	SSE	S
	NNW	NW	WNW	W	WSW	SW	SSW		
0	295	295	295	295	295	295	295	295	295
15	135	150	186	235	292	347	392	425	436
30	0	33	105	193	287	382	466	526	548
45	0	3	64	164	281	400	509	590	622
60	0	1	46	143	266	396	517	615	653
75	0	0	34	123	239	371	496	597	640
90	0	0	28	100	207	324	441	539	583

SLOPE (DEGREES)	LATITUDE 50 DEGREES NORTH, JAN. 21 ASPECT								
	N	NNE	NE	ENE	E	ESE	SE	SSE	S
	NNW	NW	WNW	W	WSW	SW	SSW		
0	151	151	151	151	151	151	151	151	151
15	24	36	65	103	149	195	236	263	273
30	0	0	19	77	150	230	304	358	377
45	0	0	8	63	149	251	353	428	455
60	0	0	4	53	144	259	377	469	502
75	0	0	3	46	132	250	377	478	515
90	0	0	2	36	117	224	351	455	492

SLOPE (DEGREES)	LATITUDE 50 DEGREES NORTH, MAR. 8 ASPECT								
	N	NNE	NE	ENE	E	ESE	SE	SSE	S
	NNW	NW	WNW	W	WSW	SW	SSW		
0	373	373	373	373	373	373	373	373	373
15	211	223	259	309	365	419	466	499	510
30	38	84	162	255	354	448	531	590	612
45	0	20	106	218	340	459	564	641	672
60	0	7	76	188	316	444	558	649	687
75	0	4	58	158	280	408	523	612	655
90	0	1	43	128	238	349	451	535	578

SLOPE (DEGREES)	LATITUDE 50 DEGREES NORTH, FEB. 9 ASPECT								
	N	NNE	NE	ENE	E	ESE	SE	SSE	S
	NNW	NW	WNW	W	WSW	SW	SSW		
0	222	222	222	222	222	222	222	222	222
15	74	88	121	167	218	269	315	345	356
30	0	2	54	128	215	305	387	445	466
45	0	0	28	106	208	323	432	515	544
60	0	0	18	89	200	325	449	549	585
75	0	0	12	77	179	308	438	546	586
90	0	0	10	61	156	271	397	506	548

SLOPE (DEGREES)	LATITUDE 50 DEGREES NORTH, MAR. 21 ASPECT								
	N	NNE	NE	ENE	E	ESE	SE	SSE	S
	NNW	NW	WNW	W	WSW	SW	SSW		
0	456	456	456	456	456	456	456	456	456
15	298	310	344	393	447	500	545	573	584
30	119	157	238	336	435	526	600	653	671
45	0	60	167	290	415	529	623	688	713
60	0	32	128	253	384	505	604	677	706
75	0	21	101	214	341	459	555	620	651
90	0	15	77	178	288	399	467	526	552

Table 7.--Daily values of direct solar radiation computed for selected slopes, aspects, and days  
at 50 degrees north latitude--*CONTINUED*  
(Cal. cm<sup>-2</sup> day<sup>-1</sup>)

LATITUDE 50 DEGREES NORTH, APR. 3									
SLOPE (DEGREES)	ASPECT								
	N	NNE	NE	ENE	E	ESE	SE	SSE	S
	NNW	NW	WNW	W	WSW	SW	SSW		
0	541	541	541	541	541	541	541	541	541
15	392	402	433	478	529	577	616	642	652
30	217	243	319	414	506	593	658	702	719
45	27	114	234	359	478	584	665	718	737
60	4	64	178	310	437	547	630	685	705
75	0	43	140	264	386	489	565	609	624
90	0	31	109	215	321	408	464	495	502

LATITUDE 50 DEGREES NORTH, MAY 21									
SLOPE (DEGREES)	ASPECT								
	N	NNE	NE	ENE	E	ESE	SE	SSE	S
	NNW	NW	WNW	W	WSW	SW	SSW		
0	780	780	780	780	780	780	780	780	780
15	692	696	710	731	759	784	802	812	817
30	556	565	595	654	712	759	788	800	798
45	382	395	471	573	656	709	737	741	737
60	182	234	372	492	584	635	649	637	626
75	101	164	295	413	497	537	535	503	478
90	69	121	230	331	399	423	399	343	308

LATITUDE 50 DEGREES NORTH, APR. 16									
SLOPE (DEGREES)	ASPECT								
	N	NNE	NE	ENE	E	ESE	SE	SSE	S
	NNW	NW	WNW	W	WSW	SW	SSW		
0	618	618	618	618	618	618	618	618	618
15	485	494	519	559	604	645	679	702	710
30	319	336	402	489	575	650	706	740	754
45	131	182	303	426	537	629	696	734	747
60	28	106	236	369	487	580	644	679	689
75	16	73	186	311	424	510	563	584	584
90	7	52	145	252	349	418	451	452	441

LATITUDE 50 DEGREES NORTH, JUN. 22									
SLOPE (DEGREES)	ASPECT								
	N	NNE	NE	ENE	E	ESE	SE	SSE	S
	NNW	NW	WNW	W	WSW	SW	SSW		
0	830	830	830	830	830	830	830	830	830
15	762	765	773	788	807	824	835	842	845
30	642	648	666	712	758	792	807	809	807
45	478	487	536	626	695	733	742	733	726
60	282	304	427	539	617	649	643	614	599
75	156	214	341	453	524	544	518	468	441
90	109	160	268	364	419	422	376	301	262

LATITUDE 50 DEGREES NORTH, MAY 1									
SLOPE (DEGREES)	ASPECT								
	N	NNE	NE	ENE	E	ESE	SE	SSE	S
	NNW	NW	WNW	W	WSW	SW	SSW		
0	700	700	700	700	700	700	700	700	700
15	588	595	614	647	683	717	744	760	765
30	435	448	498	575	649	708	752	774	780
45	253	274	387	502	603	676	723	743	746
60	87	166	305	437	544	616	655	664	662
75	49	117	245	369	470	533	557	550	532
90	35	87	192	299	383	429	434	402	377



Table 8.--Daily values of direct solar radiation computed for selected slopes, aspects, and days  
at 60 degrees north latitude  
(Cal. cm<sup>-2</sup> day<sup>-1</sup>)

LATITUDE 60 DEGREES NORTH, DEC. 22										LATITUDE 60 DEGREES NORTH, FEB. 23									
SLOPE (DEGREES)	ASPECT									SLOPE (DEGREES)	ASPECT								
	N	NNE	NE	ENE	E	ESE	SE	SSE	S		N	NNE	NE	ENE	E	ESE	SE	SSE	S
0	15	15	15	15	15	15	15	15	15	0	164	164	164	164	164	164	164	164	164
15	0	0	0	3	15	29	42	50	53	15	78	42	74	115	164	210	253	282	292
30	0	0	0	1	16	42	66	82	88	30	0	0	30	92	168	250	326	381	400
45	0	0	0	1	17	51	85	109	117	45	0	0	19	91	172	274	375	453	481
60	0	0	0	0	18	57	99	128	137	60	0	0	13	73	170	286	402	495	529
75	0	0	0	0	18	59	106	138	149	75	0	0	11	66	159	278	402	503	541
90	0	0	0	0	16	57	106	139	150	90	0	0	9	54	143	252	374	477	516

LATITUDE 60 DEGREES NORTH, JAN. 21										LATITUDE 60 DEGREES NORTH, MAR. 8									
SLOPE (DEGREES)	ASPECT									SLOPE (DEGREES)	ASPECT								
	N	NNE	NE	ENE	E	ESE	SE	SSE	S		N	NNE	NE	ENE	E	ESE	SE	SSE	S
0	41	41	41	41	41	41	41	41	41	0	244	244	244	244	244	244	244	244	244
15	0	0	2	19	42	68	92	107	113	15	87	102	139	188	242	296	341	373	384
30	0	0	0	12	46	91	135	166	177	30	0	15	76	156	247	338	419	476	498
45	0	0	0	10	49	108	170	213	228	45	0	3	53	142	249	364	469	548	579
60	0	0	0	9	50	118	193	246	264	60	0	2	43	129	246	372	489	582	619
75	0	0	0	7	49	120	203	262	282	75	0	1	34	118	228	356	479	576	618
90	0	0	0	6	45	114	199	260	281	90	0	0	30	99	204	319	436	531	574

LATITUDE 60 DEGREES NORTH, FEB. 9										LATITUDE 60 DEGREES NORTH, MAR. 21									
SLOPE (DEGREES)	ASPECT									SLOPE (DEGREES)	ASPECT								
	N	NNE	NE	ENE	E	ESE	SE	SSE	S		N	NNE	NE	ENE	E	ESE	SE	SSE	S
0	98	98	98	98	98	98	98	98	98	0	333	333	333	333	333	333	333	333	333
15	0	6	29	61	98	139	173	198	206	15	169	183	221	273	330	384	431	462	473
30	0	0	7	46	104	172	237	284	300	30	0	58	139	233	331	424	505	561	581
45	0	0	3	40	110	197	295	350	374	45	0	23	102	210	331	448	549	622	650
60	0	0	3	38	110	210	314	393	422	60	0	15	84	193	320	447	557	640	674
75	0	0	2	34	106	208	321	409	441	75	0	12	71	173	294	422	534	615	653
90	0	0	2	28	97	192	307	397	430	90	0	9	59	147	269	372	474	551	586

Table 8.--Daily values of direct solar radiation computed for selected slopes, aspects, and days  
at 60 degrees north latitude --CONTINUED  
(Cal. cm<sup>-2</sup> day<sup>-1</sup>)

LATITUDE 60 DEGREES NORTH, APR. 3											LATITUDE 60 DEGREES NORTH, MAY 21										
SLOPE (DEGREES)	ASPECT										SLOPE (DEGREES)	ASPECT									
	N	NNE NNW	NE NW	ENE WNW	E W	ESE WSW	SE SW	SSE SSW	S	N		NNE NNW	NE NW	ENE WNW	E W	ESE WSW	SE SW	SSE SSW	S		
0	429	429	429	429	429	429	429	429	429	0	733	733	733	733	733	733	733	733	733		
15	267	279	314	364	421	476	520	550	561	15	625	631	649	678	714	748	773	789	792		
30	88	126	215	315	417	509	583	635	655	30	474	487	525	606	684	746	786	804	808		
45	5	60	163	285	410	524	617	680	704	45	291	309	421	545	649	721	762	773	774		
60	1	41	135	259	390	512	610	679	705	60	163	219	355	491	599	669	700	700	696		
75	0	31	114	229	355	474	571	633	658	75	122	176	302	430	529	588	604	586	571		
90	0	24	92	194	307	411	493	548	566	90	98	141	250	359	442	482	477	437	418		
LATITUDE 60 DEGREES NORTH, APR. 16											LATITUDE 60 DEGREES NORTH, JUN. 22										
SLOPE (DEGREES)	ASPECT										SLOPE (DEGREES)	ASPECT									
	N	NNE NNW	NE NW	ENE WNW	E W	ESE WSW	SE SW	SSE SSW	S	N		NNE NNW	NE NW	ENE WNW	E W	ESE WSW	SE SW	SSE SSW	S		
0	524	524	524	524	524	524	524	524	524	0	802	802	802	802	802	802	802	802	802		
15	373	383	414	462	515	564	604	631	638	15	716	721	733	753	781	806	825	835	837		
30	197	219	305	407	504	592	657	697	711	30	582	591	615	677	743	793	818	830	832		
45	46	116	238	367	491	597	676	723	738	45	408	421	493	609	701	757	778	779	776		
60	26	84	202	335	464	573	654	701	714	60	248	295	418	548	642	693	703	688	681		
75	19	67	172	295	420	525	598	633	642	75	193	238	358	479	564	602	593	560	541		
90	13	55	141	252	361	448	503	528	525	90	156	195	297	400	467	486	455	401	380		
LATITUDE 60 DEGREES NORTH, MAY 1																					
SLOPE (DEGREES)	ASPECT										SLOPE (DEGREES)	ASPECT									
	N	NNE NNW	NE NW	ENE WNW	E W	ESE WSW	SE SW	SSE SSW	S	N		NNE NNW	NE NW	ENE WNW	E W	ESE WSW	SE SW	SSE SSW	S		
0	625	625	625	625	625	625	625	625	625												
15	491	499	524	564	611	654	689	709	717												
30	323	340	404	499	592	667	723	754	762												
45	134	188	320	451	566	659	722	754	761												
60	74	137	267	405	527	621	681	707	710												
75	55	110	227	357	472	558	606	617	612												
90	39	87	167	300	399	467	495	489	474												

Table 9.--Yearly values of direct solar radiation computed for selected slopes and aspects at 0 degrees north latitude

(Cal. cm<sup>-2</sup> year<sup>-1</sup>)

LATITUDE 0 DEGREES NORTH ASPECTS	ANNUAL POTENTIAL RADIATION						
	SLOPE (DEGREE)						
	0	15	30	45	60	75	90
N	266271	256334	229516	187660	135307	83909	43995
NNE / NNW	266271	256597	230996	192003	140473	95031	53373
NE / NW	266271	257979	234879	201447	161632	118098	82560
ENE / NNW	266271	258801	238959	210727	176834	140440	104574
E / W	266271	260019	241296	215236	183612	148798	113425
ESE / WSW	266271	259361	240078	212076	178282	141855	105791
SE / SW	266271	261862	237051	204145	164560	123132	84929
SSE / SSW	266271	258176	233925	195919	148568	99177	57749
S	266271	258012	232740	192201	140671	88911	47252

Table 10.--Yearly values of direct solar radiation computed for selected slopes and aspects at 10 degrees north latitude

(Cal. cm<sup>-2</sup> year<sup>-1</sup>)

LATITUDE 10 DEGREES NORTH ASPECTS	ANNUAL POTENTIAL RADIATION						
	SLOPE (DEGREE)						
	0	15	30	45	60	75	90
N	261965	242164	206245	157690	105146	63357	30089
NNE / NNW	261965	243249	209419	164709	115810	72519	40205
NE / NW	261965	246112	217384	180345	140062	101891	69483
ENE / NNW	261965	250274	227466	197719	164061	129373	96166
E / W	261965	254935	237031	211500	180610	146614	111894
ESE / WSW	261965	258964	243388	218066	185958	149742	112461
SE / SW	261965	261728	246536	219193	182699	141054	99587
SSE / SSW	261965	263223	248257	217949	175634	126719	79536
S	261965	264061	248269	216702	171396	117984	72667

Table 11.--Yearly values of direct solar radiation computed for selected slopes and aspects at 20 degrees north latitude  
(Cal. cm<sup>-2</sup> year<sup>-1</sup>)

LATITUDE 20 DEGREES NORTH ASPECTS	ANNUAL POTENTIAL RADIATION						
	SLOPE (DEGREE)						
	0	15	30	45	60	75	90
N	249369	219652	175631	122819	77514	41185	14880
NNE / NNW	249369	221412	180504	132450	86881	51202	27913
NE / NW	249369	226473	192752	153507	115866	82833	56588
ENE / WNW	249369	233768	208961	179137	147375	116007	86441
E / W	249369	241992	225062	201375	172872	141269	108516
ESE / WSW	249369	249935	238871	217760	188672	154584	117834
SE / SW	249369	256243	248389	228023	196278	157035	114599
SSE / SSW	249369	260492	255199	233695	198527	153206	103707
S	249369	262107	256993	234508	197870	148588	96923

Table 12.--Yearly values of direct solar radiation computed for selected slopes and aspects at 30 degrees north latitude  
(Cal. cm<sup>-2</sup> year<sup>-1</sup>)

LATITUDE 30 DEGREES NORTH ASPECTS	ANNUAL POTENTIAL RADIATION						
	SLOPE (DEGREE)						
	0	15	30	45	60	75	90
N	228598	191181	141938	93370	54585	24533	9251
NNE / NNW	228598	193787	148426	101812	63939	36375	21647
NE / NW	228598	200880	164701	127474	94741	68680	48453
ENE / WNW	228598	211217	186275	158918	131503	104854	79751
E / W	228598	222803	208487	188636	164169	136621	107166
ESE / WSW	228598	233857	228065	212889	188686	158766	124259
SE / SW	228598	243088	243293	230963	205901	171372	130713
SSE / SSW	228598	249277	253512	241794	215287	176287	129124
S	228598	251410	257090	245235	217802	176410	125613

Table 13.--Yearly values of direct solar radiation computed for selected slopes  
and aspects at 40 degrees north latitude  
(Cal. cm<sup>-2</sup> year<sup>-1</sup>)

LATITUDE 40 DEGREES NORTH ASPECTS	ANNUAL POTENTIAL RADIATION						
	SLOPE (DEGREE)						
	0	15	30	45	60	75	90
N	201947	158569	109293	68691	35676	14296	8075
NNE / NNW	201947	161733	115743	76364	45321	27491	18235
NE / NW	201947	170272	134282	101682	76253	57241	42286
ENE / NNW	201947	182693	159363	136210	114381	93292	72747
E / W	201947	196743	185602	170586	151501	128594	103446
ESE / WSW	201947	210420	209707	200575	182540	157822	126960
SE / SW	201947	221738	229278	224469	206725	178720	142449
SSE / SSW	201947	229203	241788	239559	221816	190753	149109
S	201947	231739	246356	244610	226325	194083	149746

Table 14.--Yearly values of direct solar radiation computed for selected slopes  
and aspects at 50 degrees north latitude  
(Cal. cm<sup>-2</sup> year<sup>-1</sup>)

LATITUDE 50 DEGREES NORTH ASPECTS	ANNUAL POTENTIAL RADIATION						
	SLOPE (DEGREE)						
	0	15	30	45	60	75	90
N	169828	124666	82782	48811	22240	12272	8410
NNE / NNW	169828	128106	88193	55562	33159	23182	17061
NE / NW	169828	137288	104883	79522	62012	49125	38297
ENE / NNW	169828	150590	130706	113523	97962	82748	66776
E / W	169828	165904	158681	149080	135898	118559	98199
ESE / WSW	169828	180801	184942	181678	170478	151768	126043
SE / SW	169828	193182	206476	208569	198275	178068	147813
SSE / SSW	169828	201357	220488	225999	216670	194404	160145
S	169828	204293	225158	231811	222792	199215	163289



Table 15.--Yearly values of direct solar radiation computed for selected slopes and aspects at 60 degrees north latitude

(Cal.  $\text{cm}^{-2}$  year $^{-1}$ )

LATITUDE 60 DEGREES NORTH ASPECTS	ANNUAL POTENTIAL RADIATION						
	SLOPE (DEGREE)						
	0	15	30	45	60	75	90
N	135941	96813	61924	34001	19553	14824	11711
NNE    NNW	135941	99480	66930	41292	29335	23506	18920
NE / NW	135941	107188	81395	64044	53842	45761	37822
ENE / WNW	135941	119111	104440	94079	85025	74867	62965
E / W	135941	133288	130203	126125	118704	107026	91477
ESE / WSW	135941	147272	154677	156417	151032	138302	118357
SE / SW	135941	158862	174569	181149	177270	163716	140167
SSE / SSW	135941	166463	187404	196841	194026	178905	152643
S	135941	169028	191739	202086	199718	183742	156459



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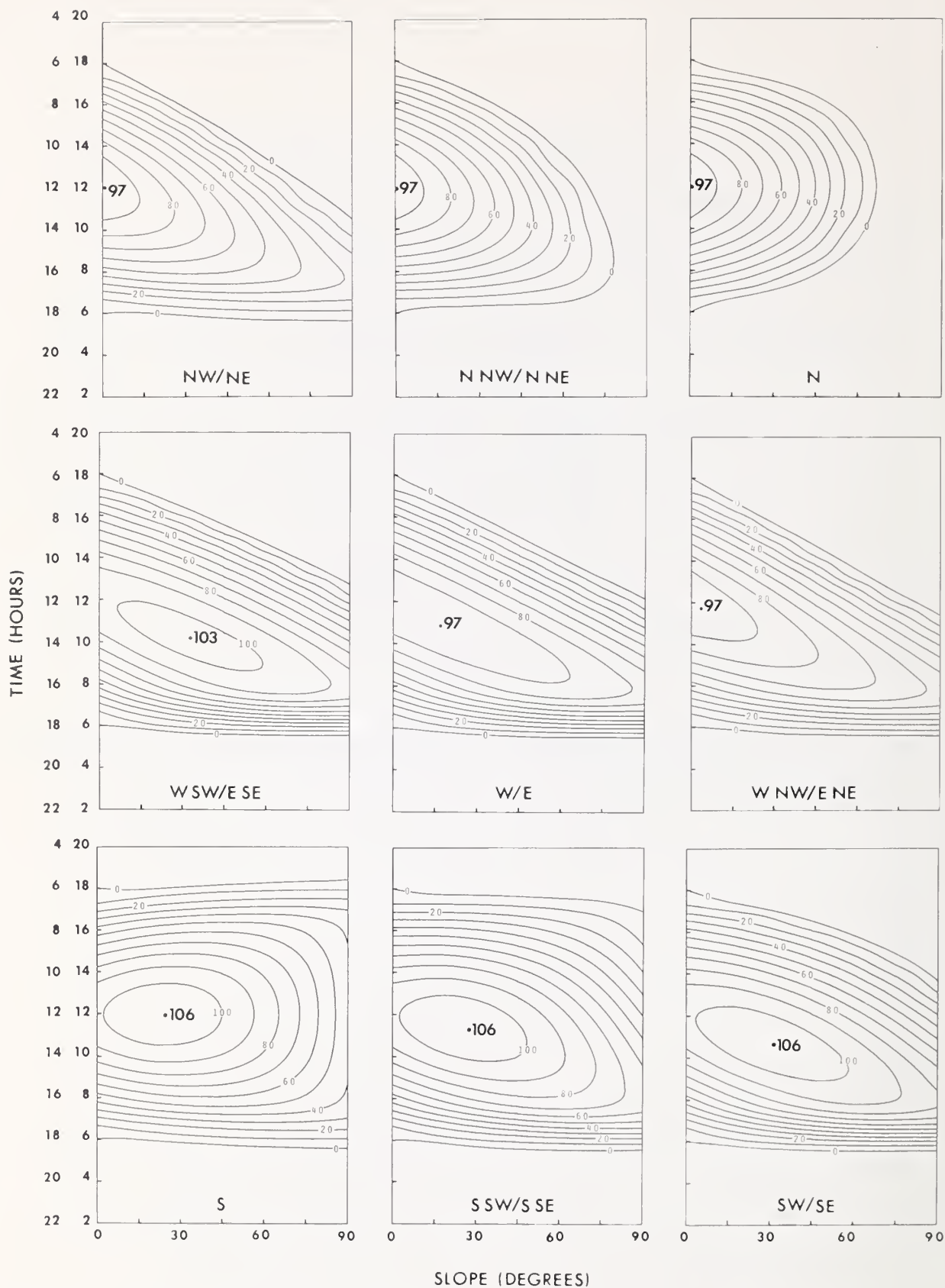


Figure 2.—Isograms of hourly values of direct solar radiation for various slopes at 0 degrees north latitude on December 22. For westerly exposures, the time is read from top to bottom (left time axis); for easterly exposures, the time is read from bottom to top (right time axis).

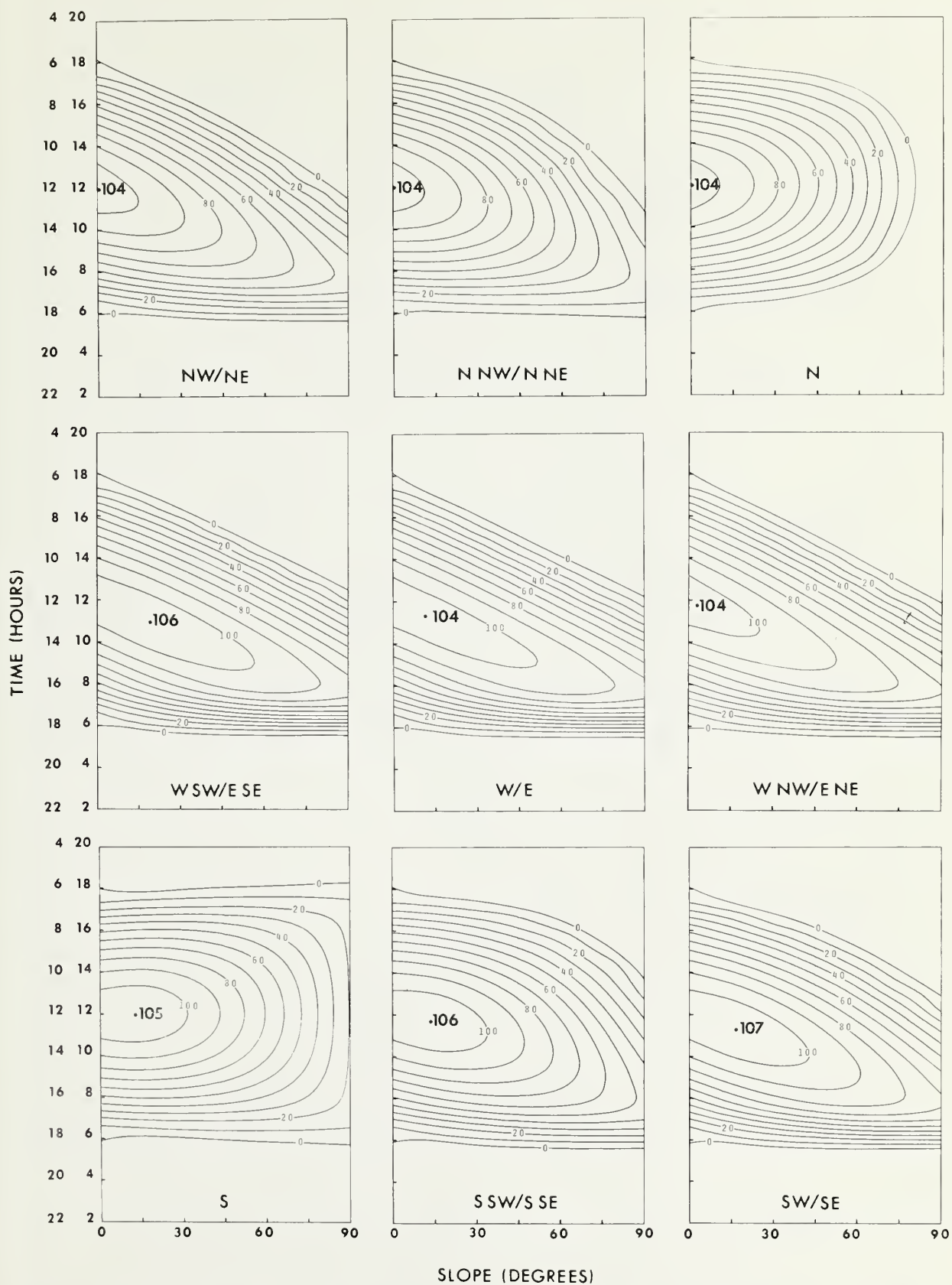


Figure 3.—Isograms of hourly values of direct solar radiation for various slopes at 0 degrees north latitude on February 23 and October 20. For westerly exposures, the time is read from top to bottom (left time axis); for easterly exposures, the time is read from bottom to top (right time axis).

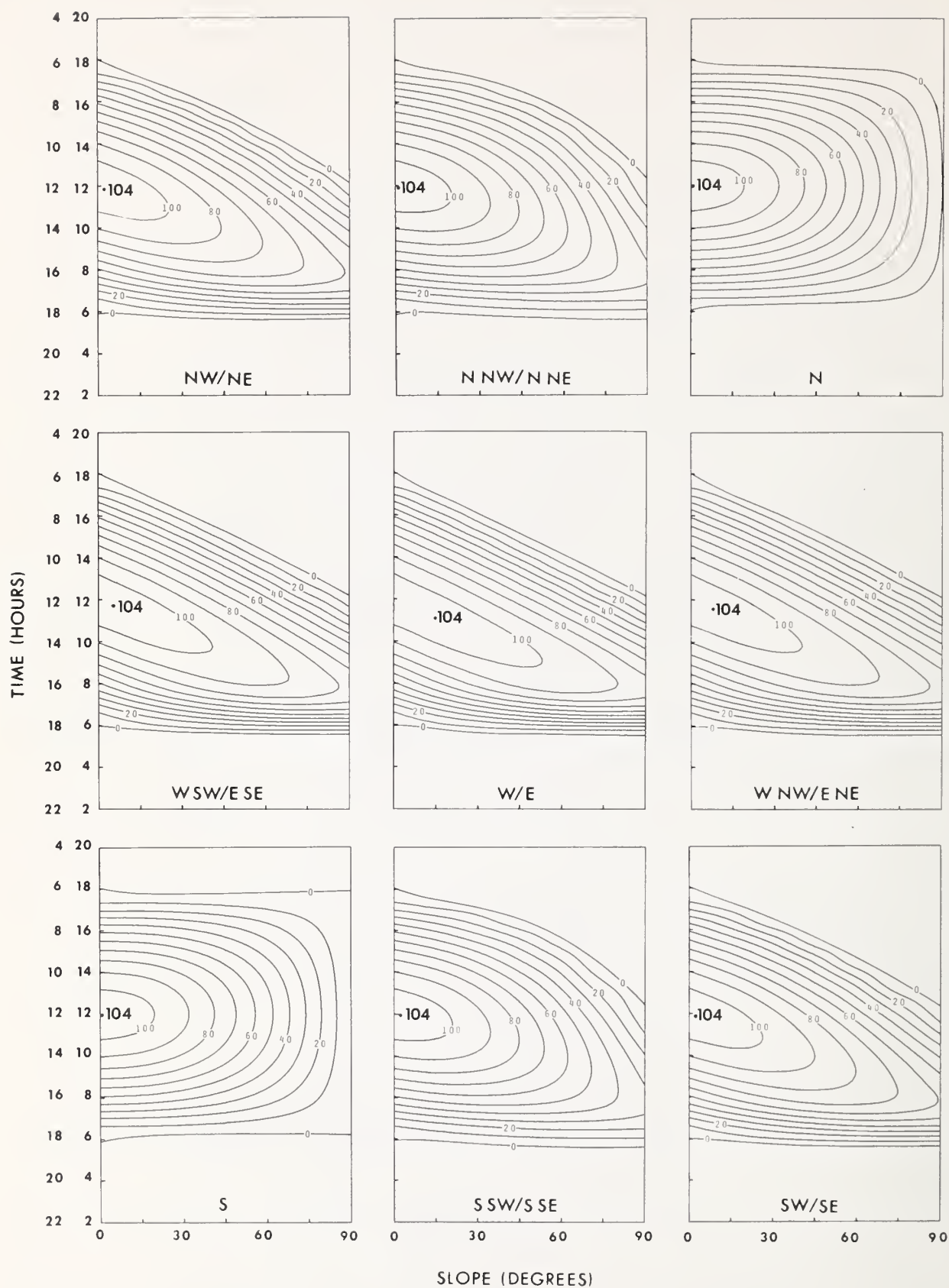


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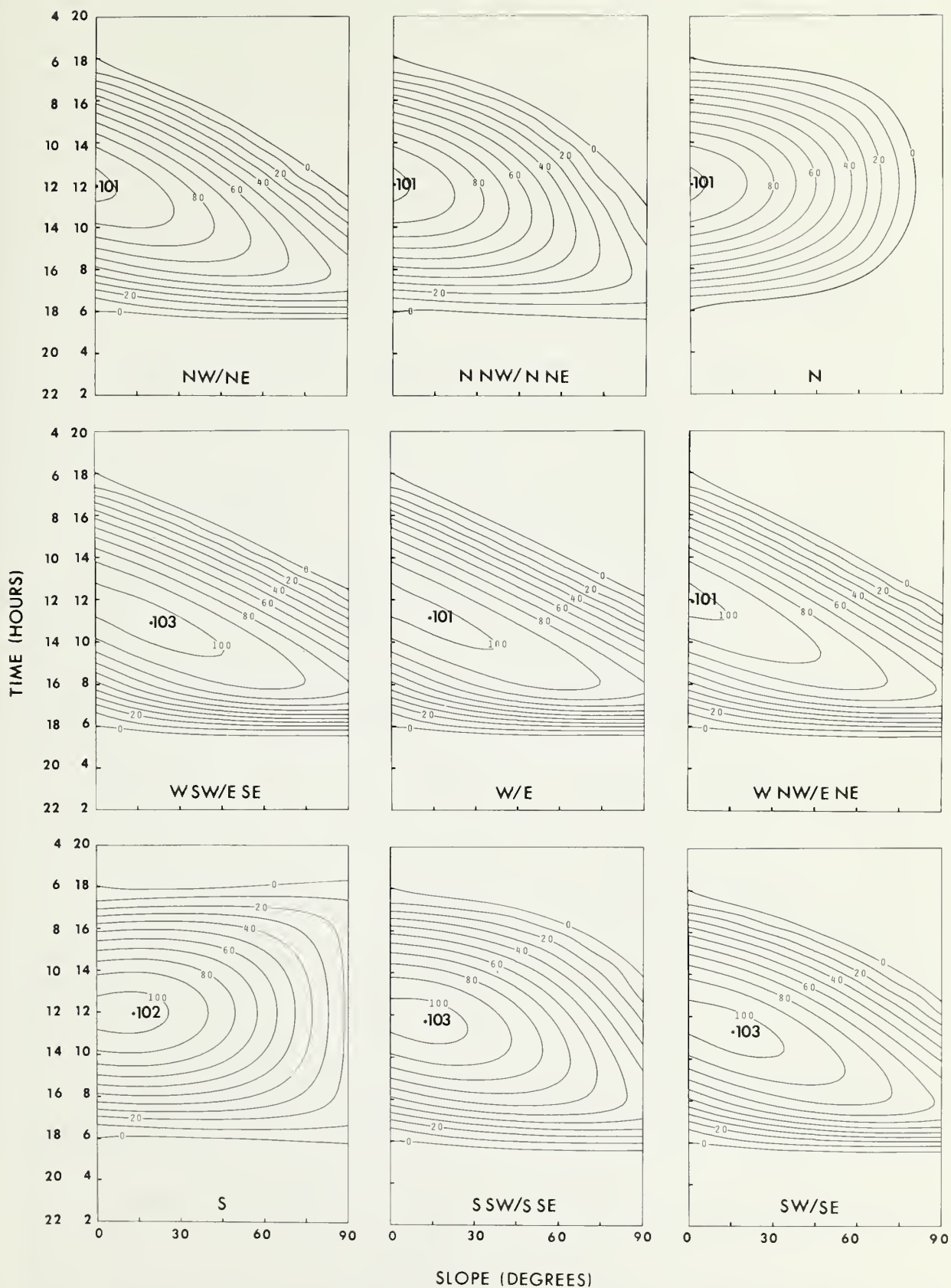


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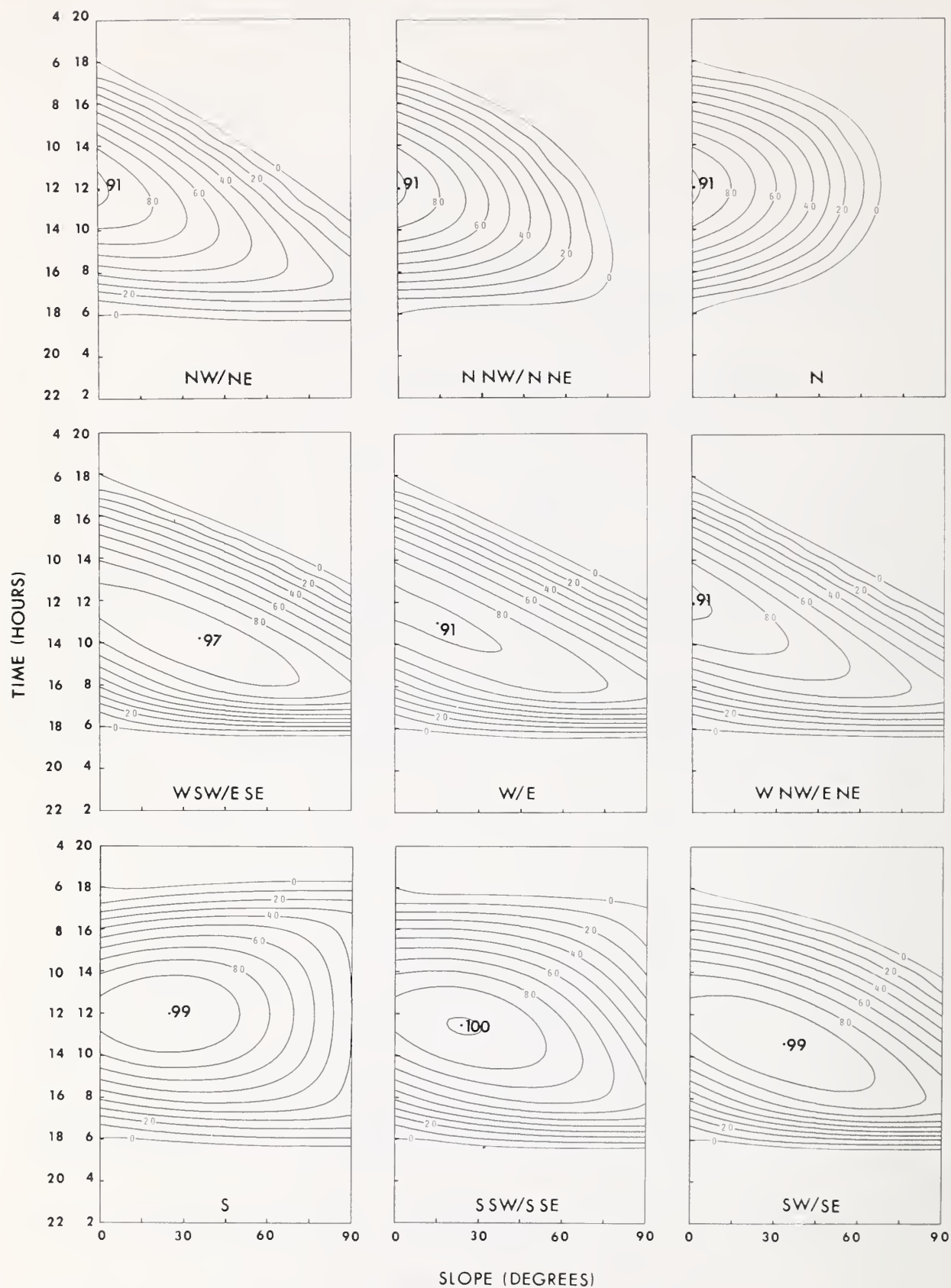


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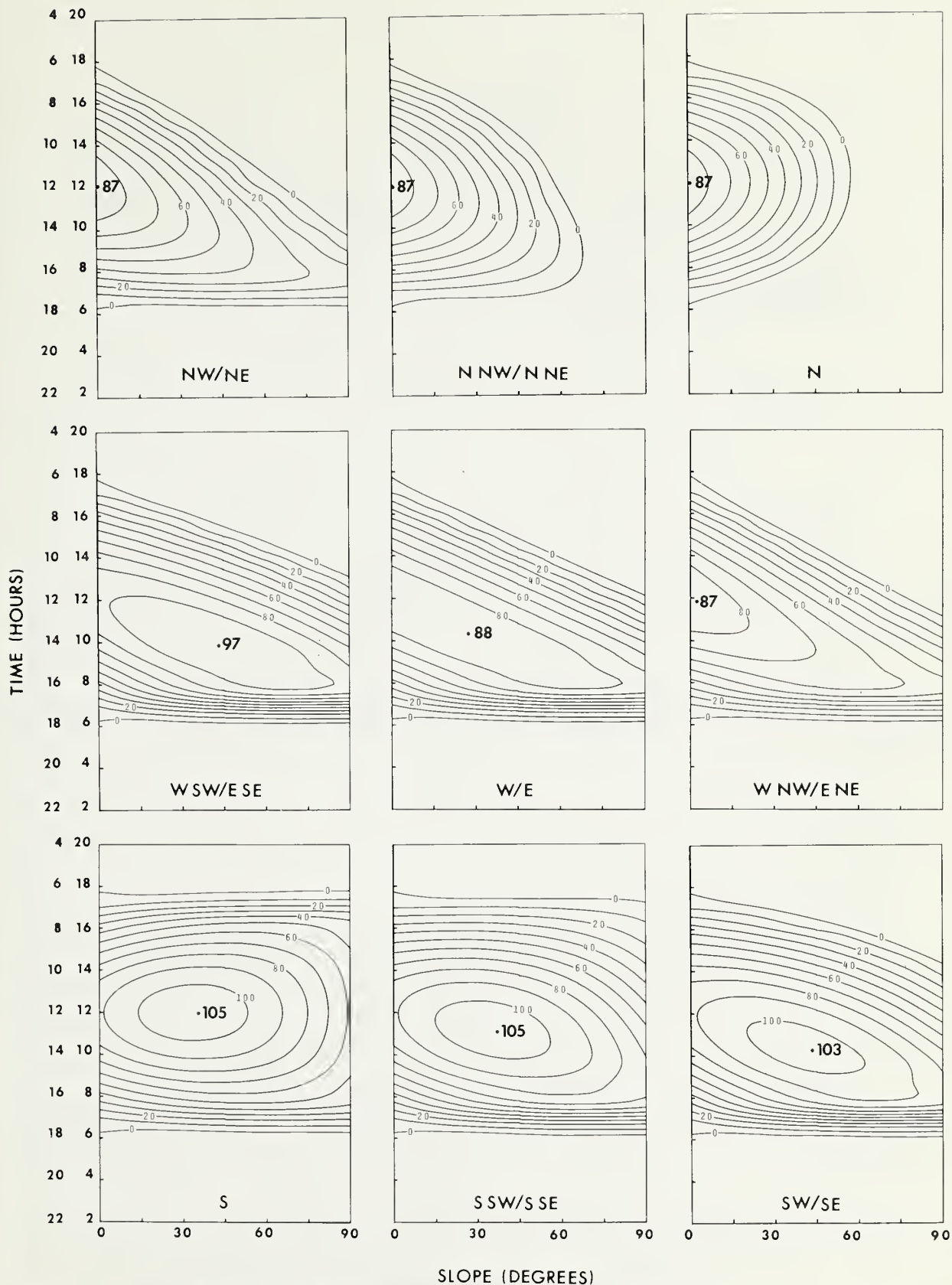


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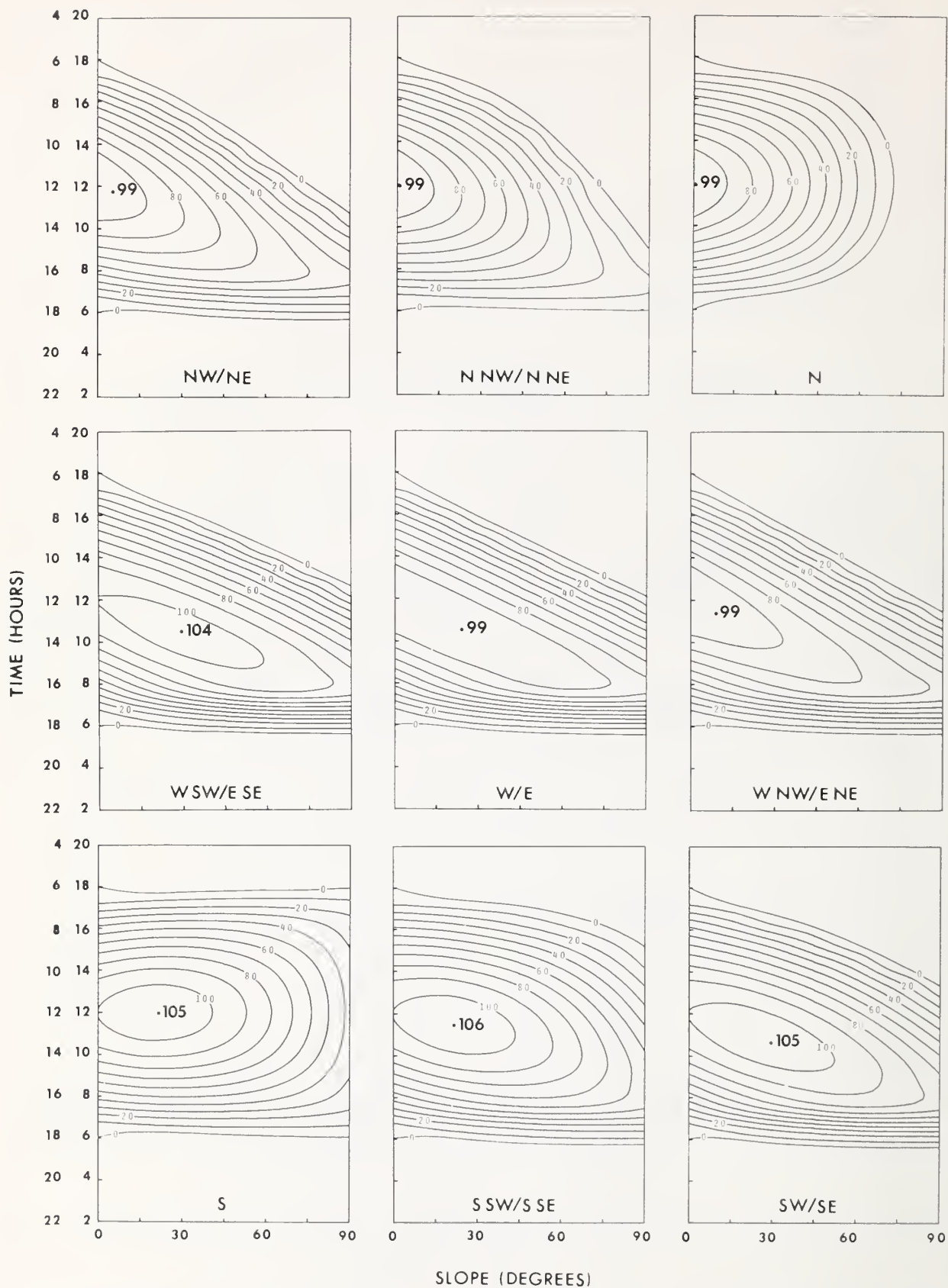


Figure 8.—Isograms of hourly values of direct solar radiation for various slopes at 10 degrees north latitude on February 23 and October 20. For westerly exposures, the time is read from top to bottom (left time axis); for easterly exposures, the time is read from bottom to top (right time axis).



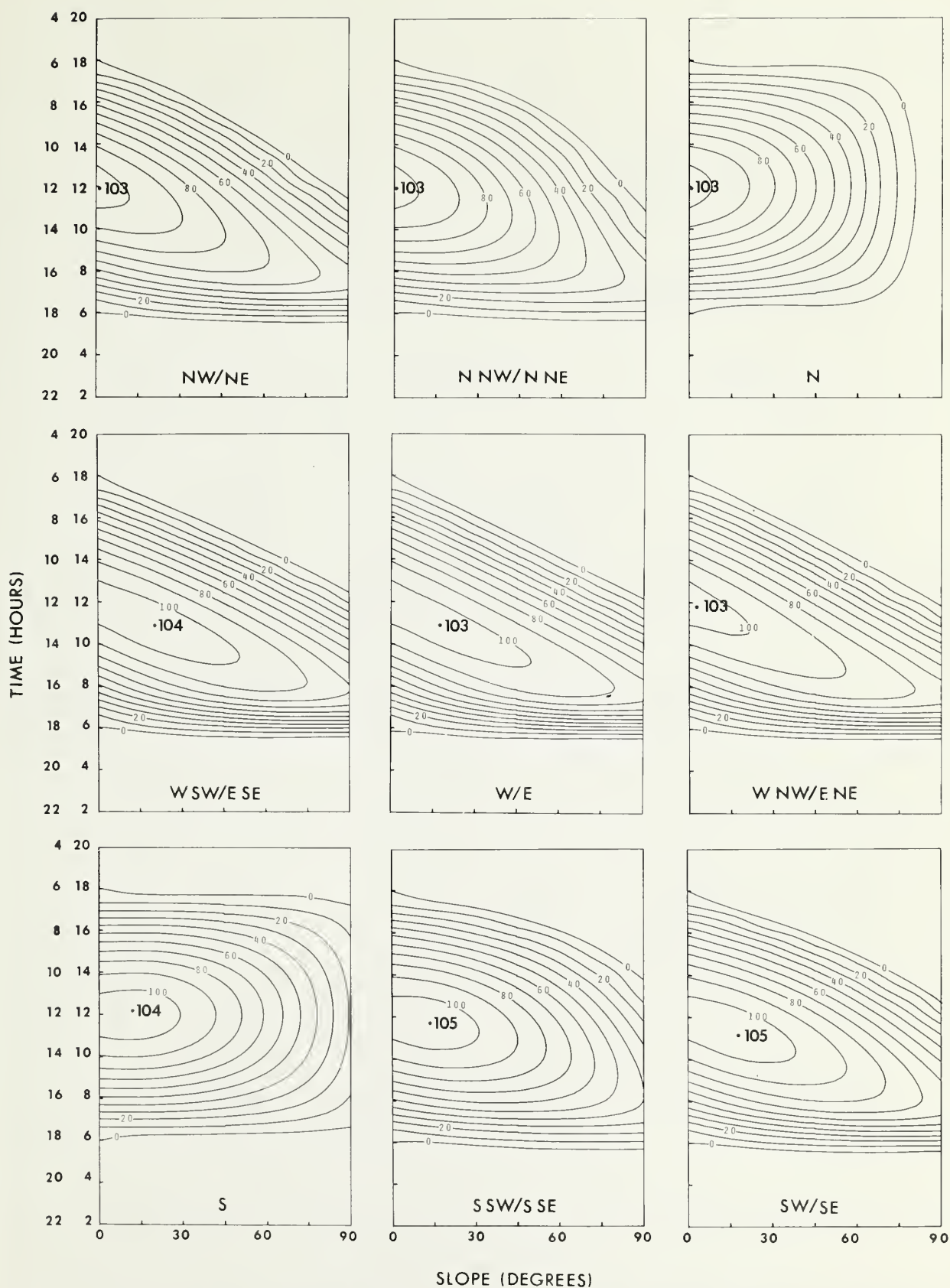


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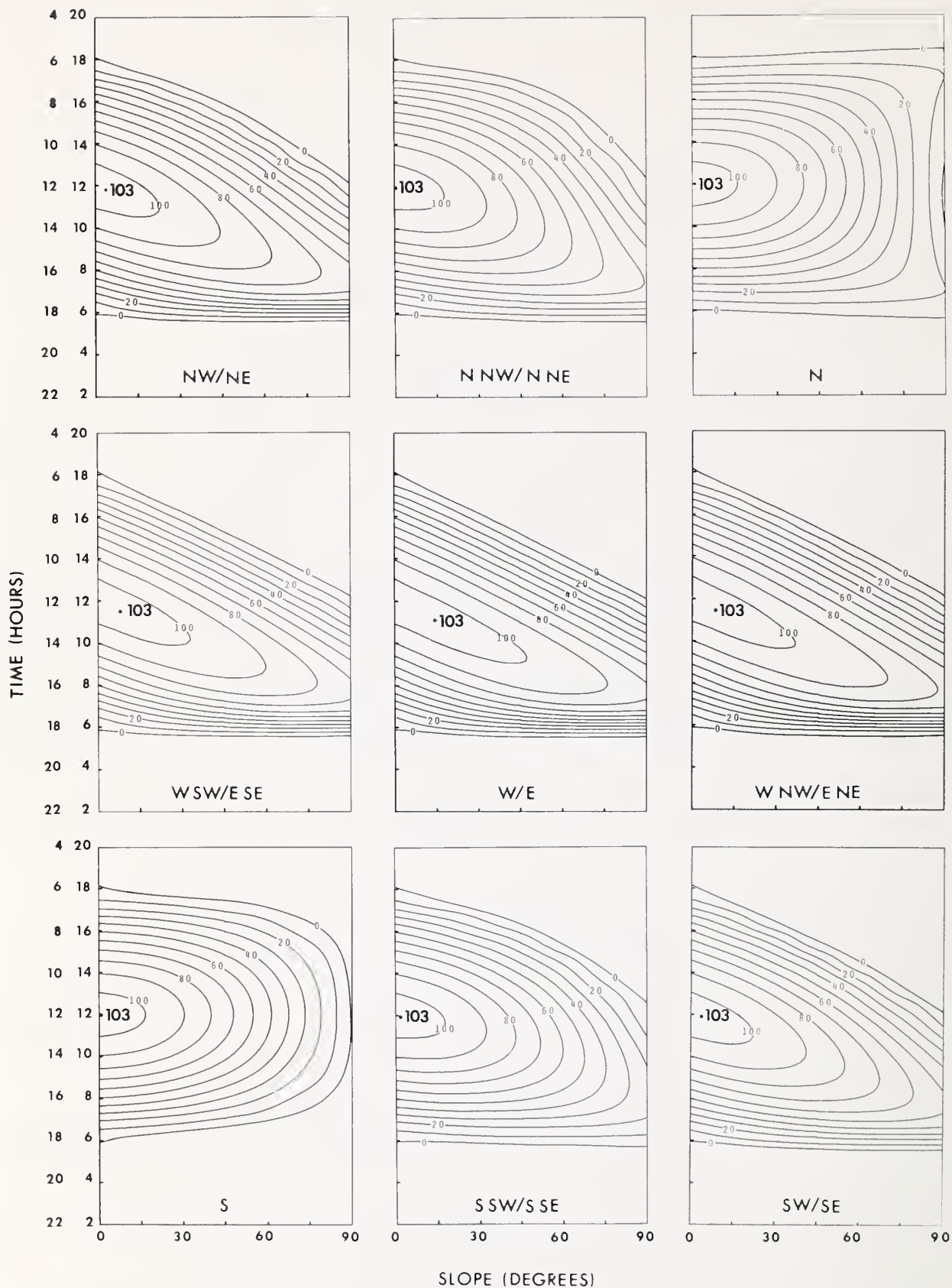


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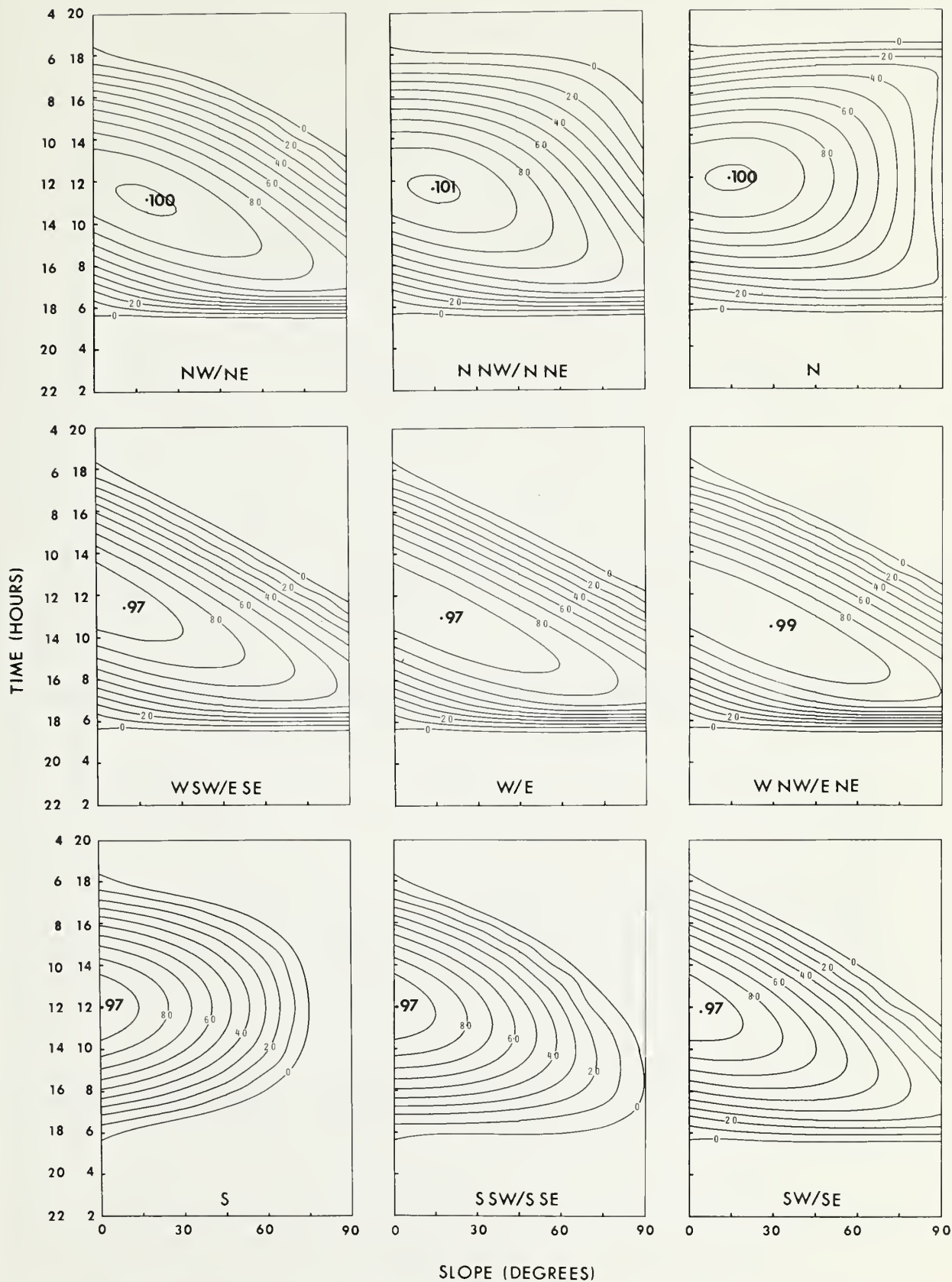


Figure 11.—Isograms of hourly values of direct solar radiation for various slopes at 10 degrees north latitude on June 22. For westerly exposures, the time is read from top to bottom (left time axis); for easterly exposures, the time is read from bottom to top (right time axis).

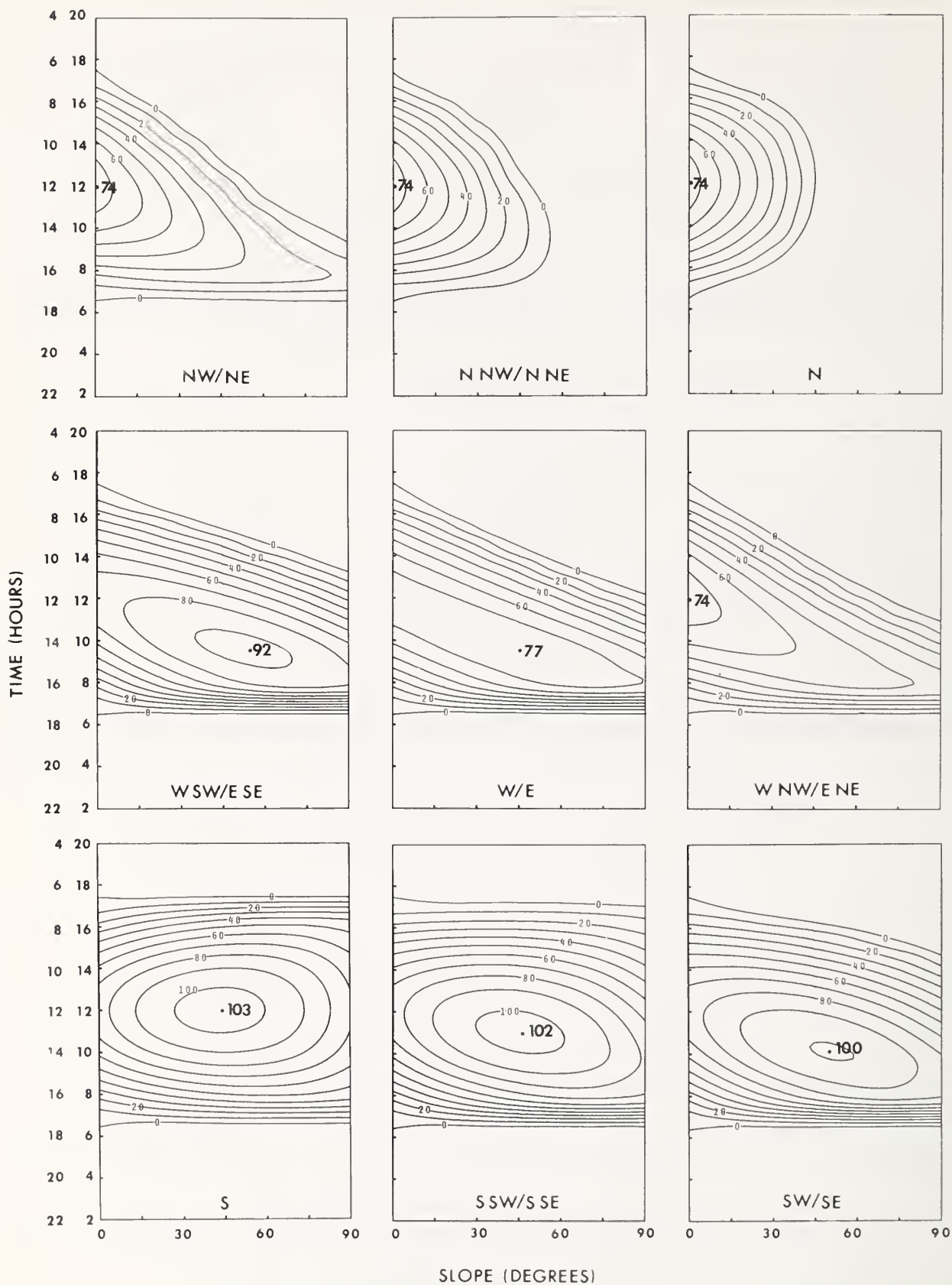


Figure 12.—Isograms of hourly values of direct solar radiation for various slopes at 20 degrees north latitude on December 22. For westerly exposures, the time is read from top to bottom (left time axis); for easterly exposures, the time is read from bottom to top (right time axis).



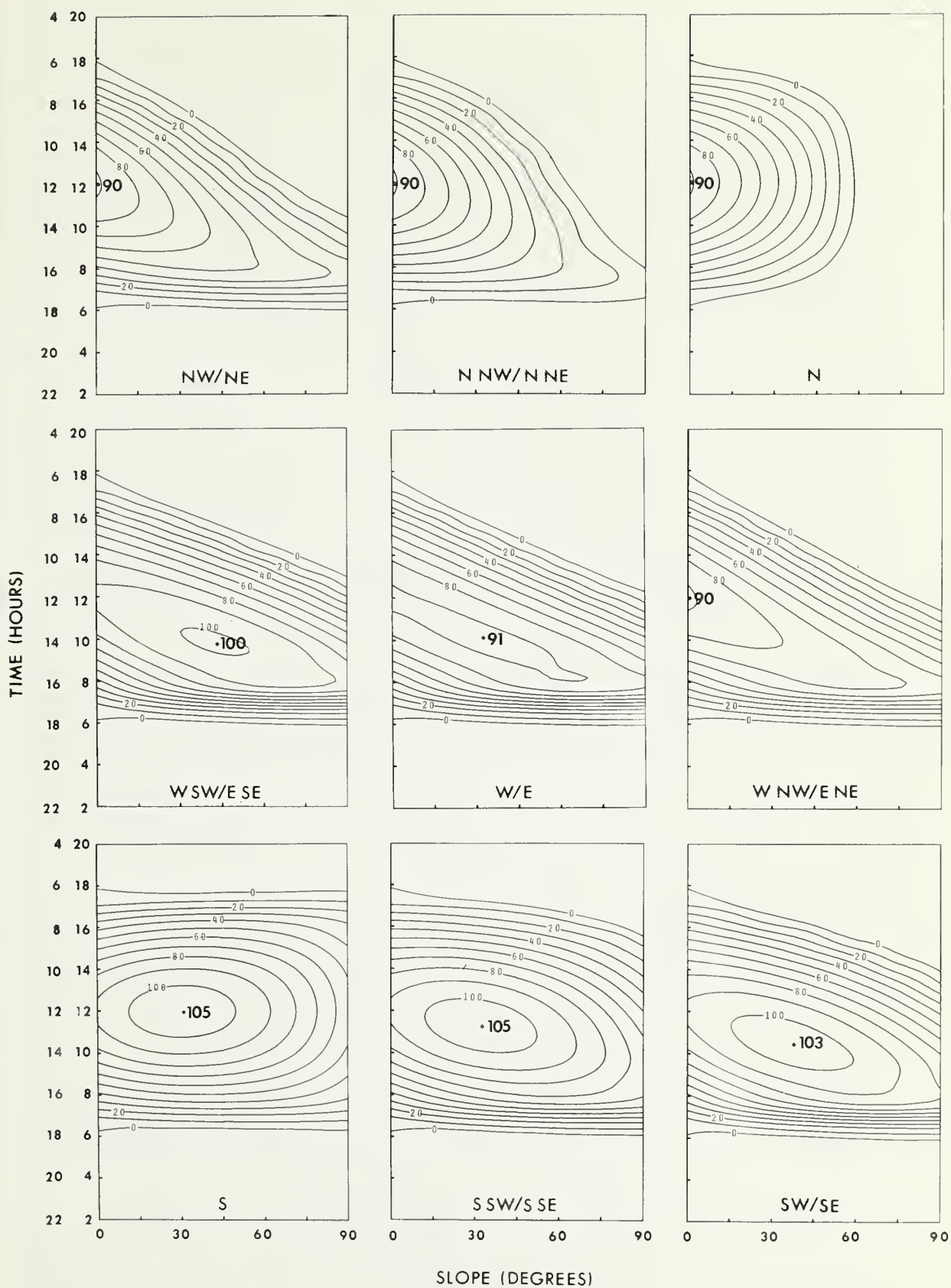


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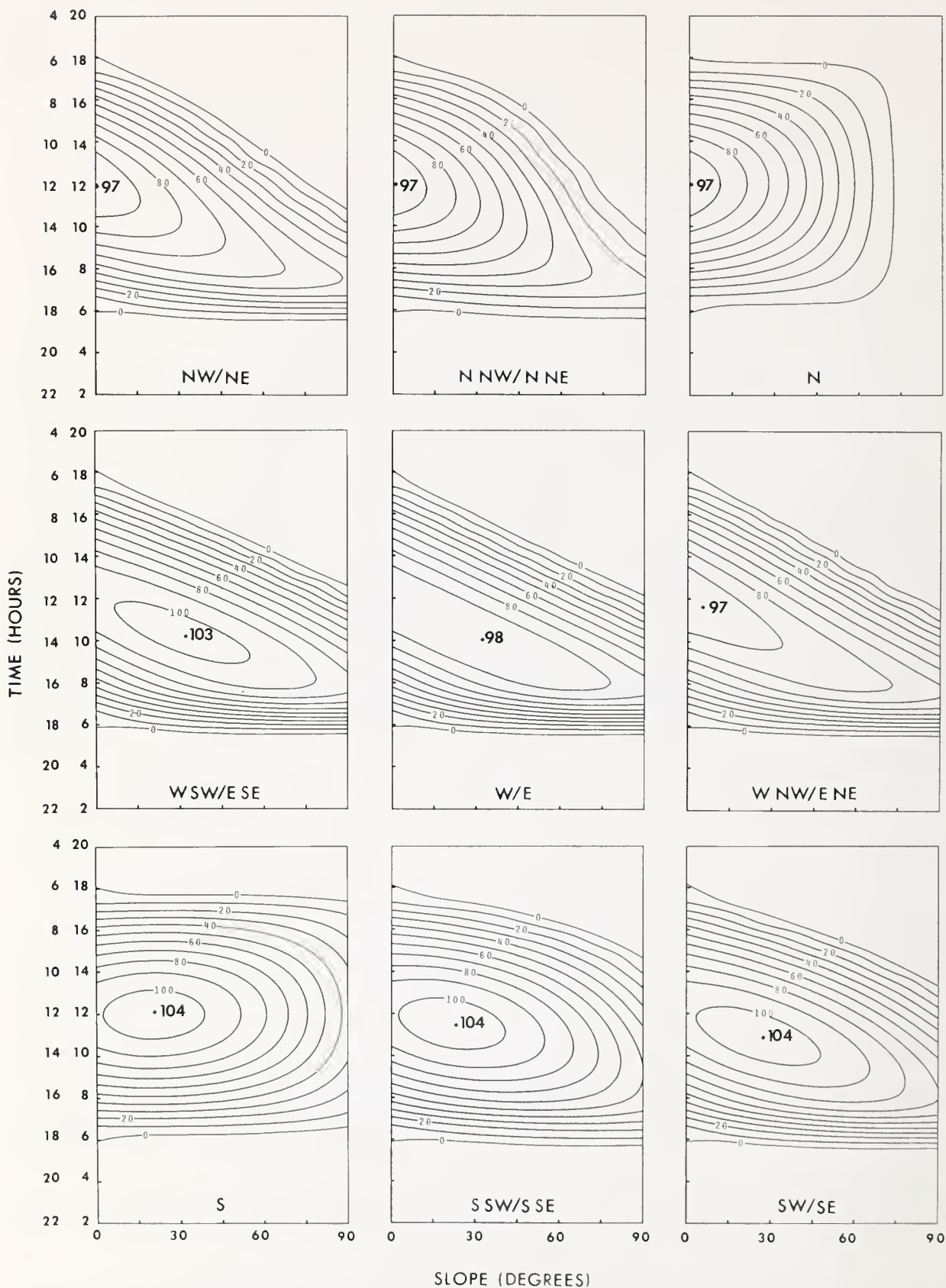


Figure 14.—Isograms of hourly values of direct solar radiation for various slopes at 20 degrees north latitude on March 21 and September 23. For westerly exposures, the time is read from top to bottom (left time axis); for easterly exposures, the time is read from bottom to top (right time axis).

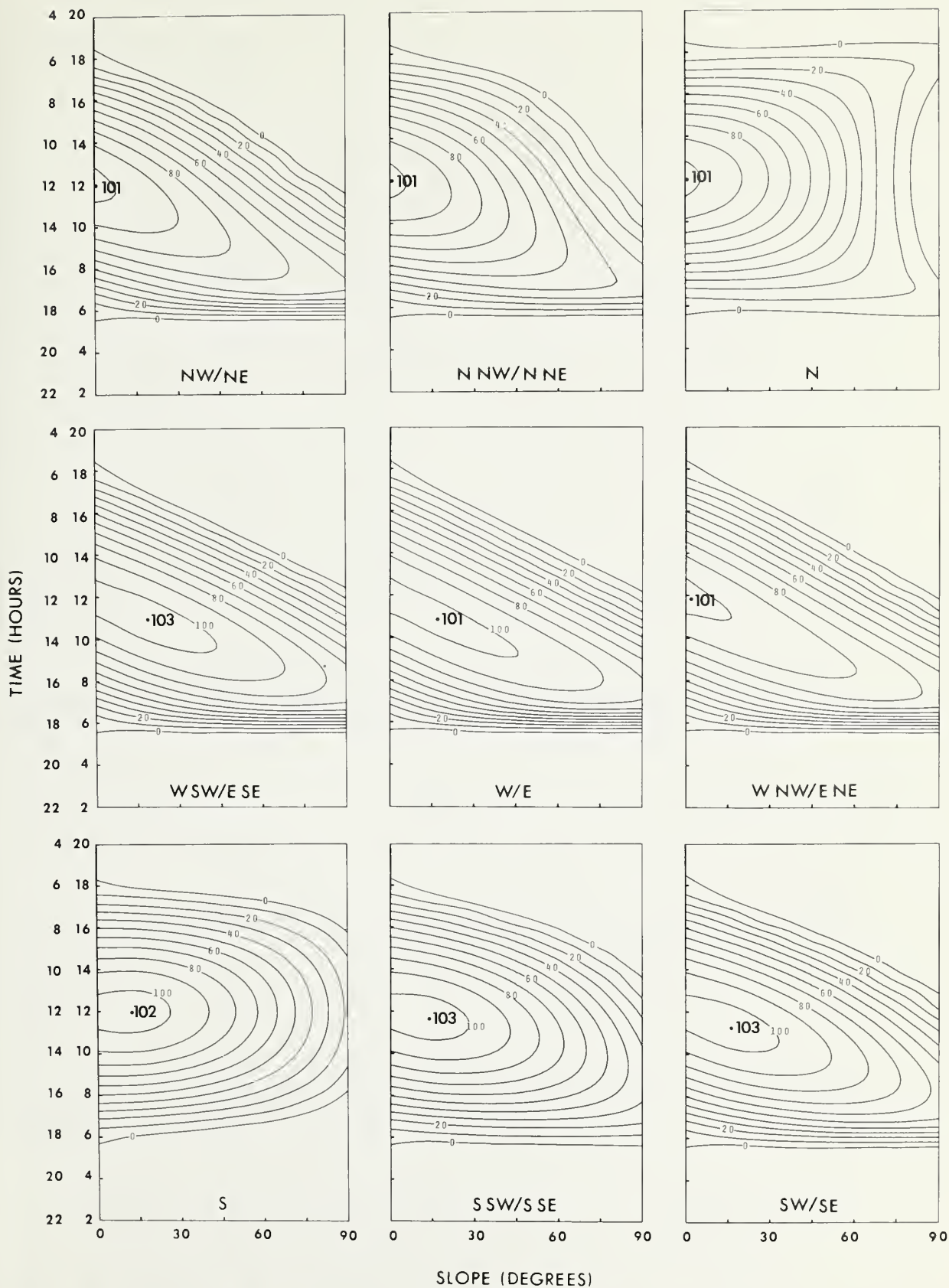


Figure 15.—Isograms of hourly values of direct solar radiation for various slopes at 20 degrees north latitude on April 16 and August 28. For westerly exposures, the time is read from top to bottom (left time axis); for easterly exposures, the time is read from bottom to top (right time axis).



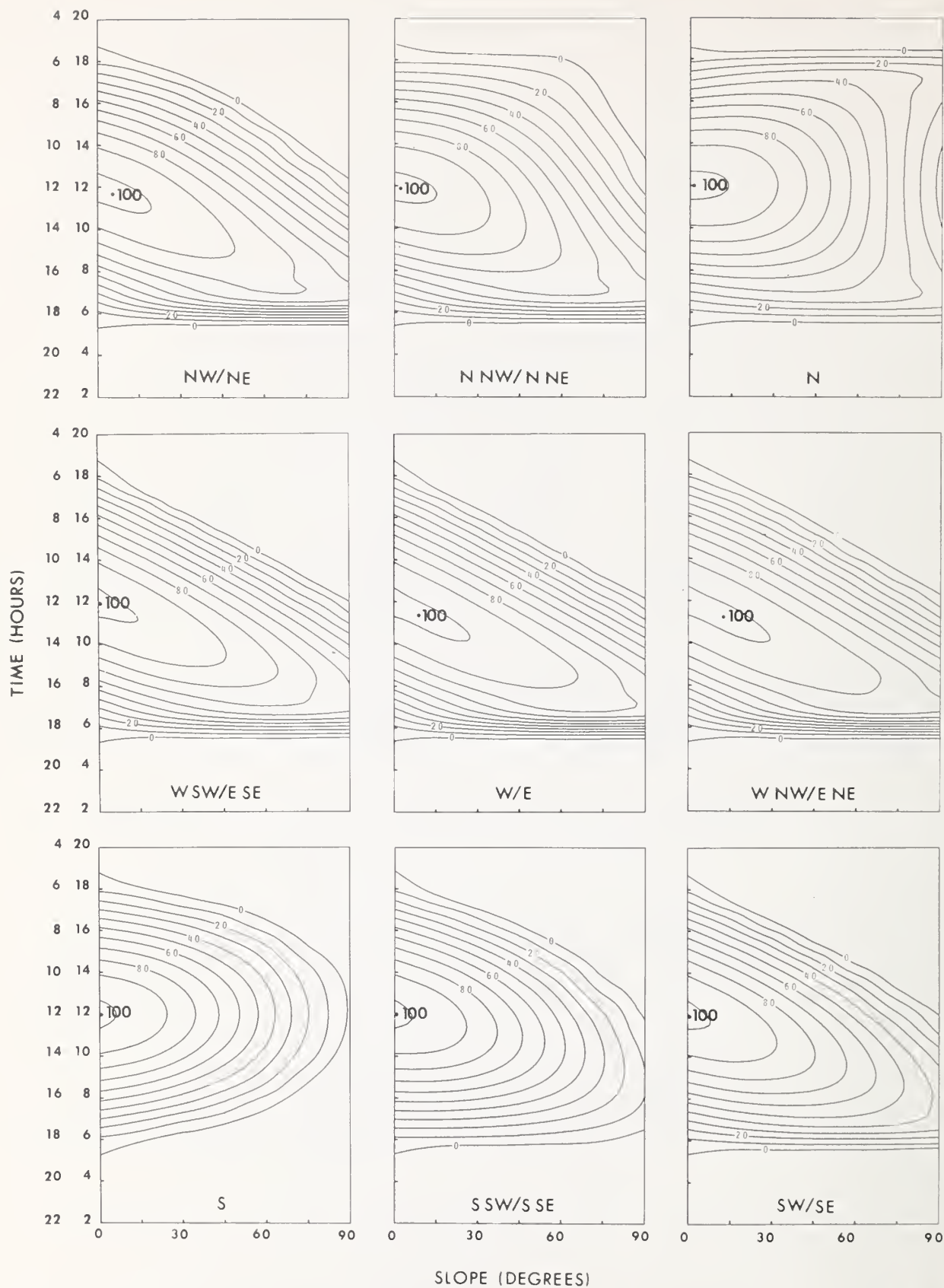


Figure 16.—Isograms of hourly values of direct solar radiation for various slopes at 20 degrees north latitude on June 22. For westerly exposures, the time is read from top to bottom (left time axis); for easterly exposures, the time is read from bottom to top (right time axis).

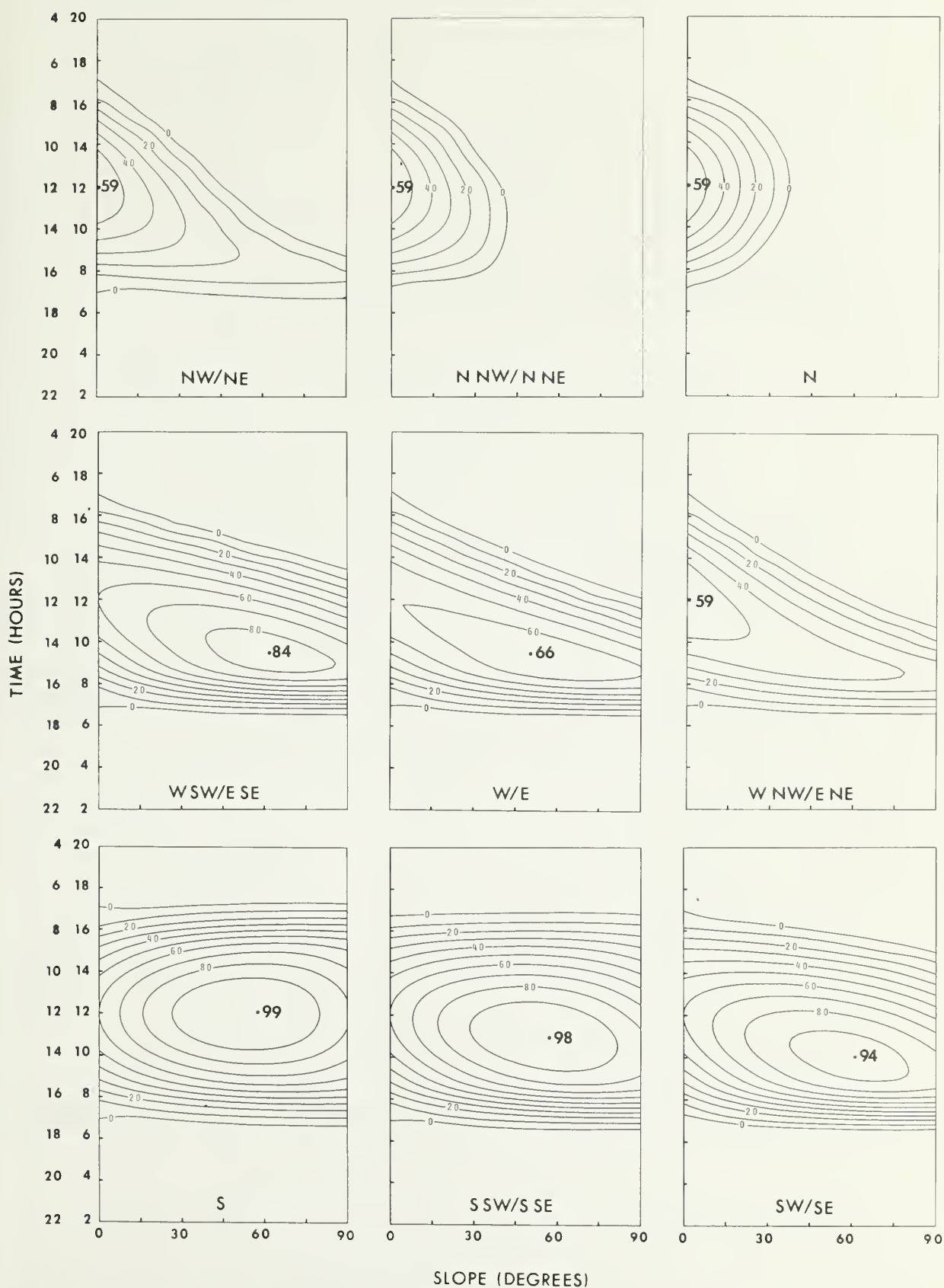


Figure 17.—Isograms of hourly values of direct solar radiation for various slopes at 30 degrees north latitude on December 22. For westerly exposures, the time is read from top to bottom (left time axis); for easterly exposures, the time is read from bottom to top (right time axis).

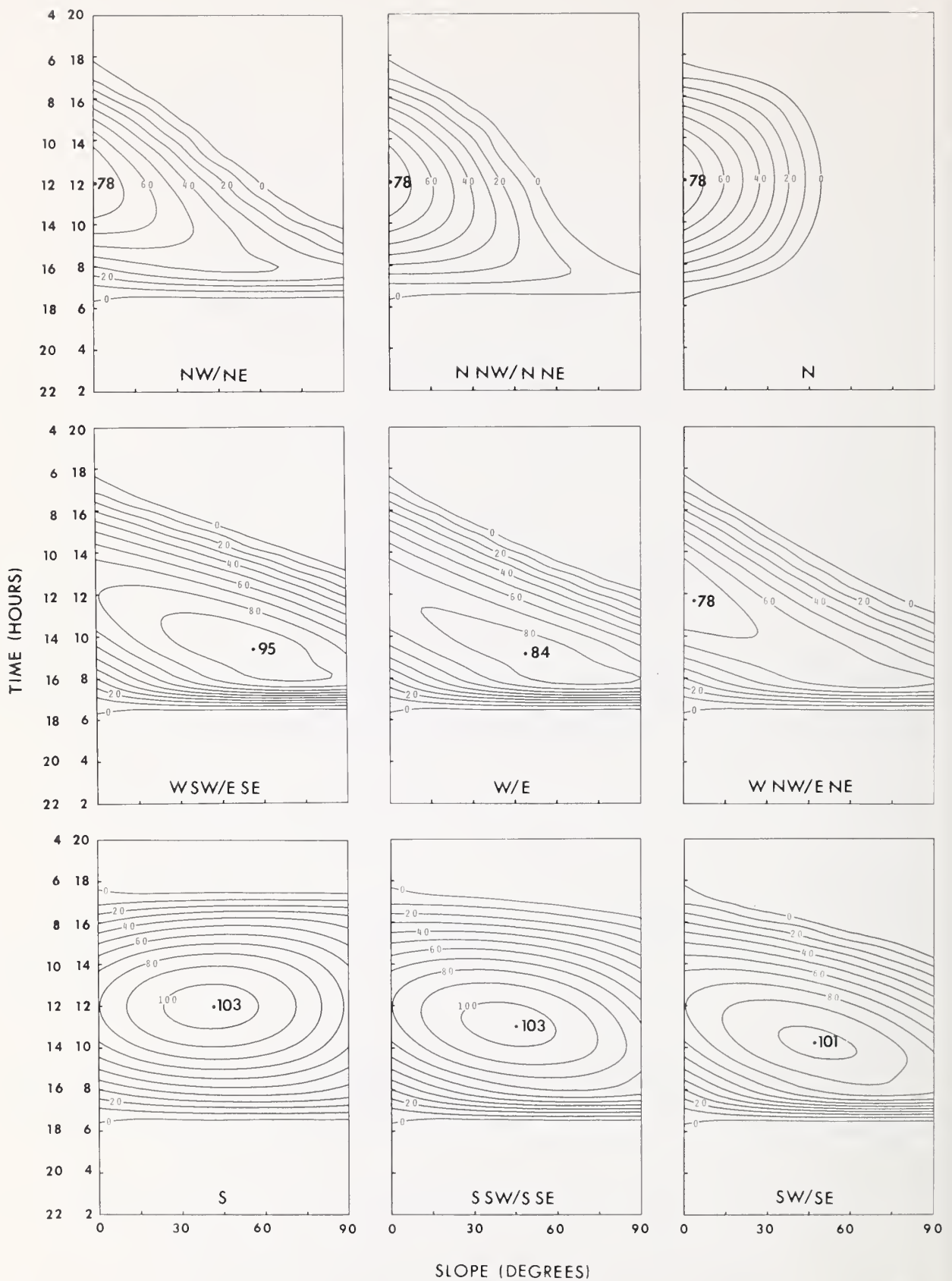


Figure 18.—Isograms of hourly values of direct solar radiation for various slopes at 30 degrees north latitude on February 23 and October 20. For westerly exposures, the time is read from top to bottom (left time axis); for easterly exposures, the time is read from bottom to top (right time axis).

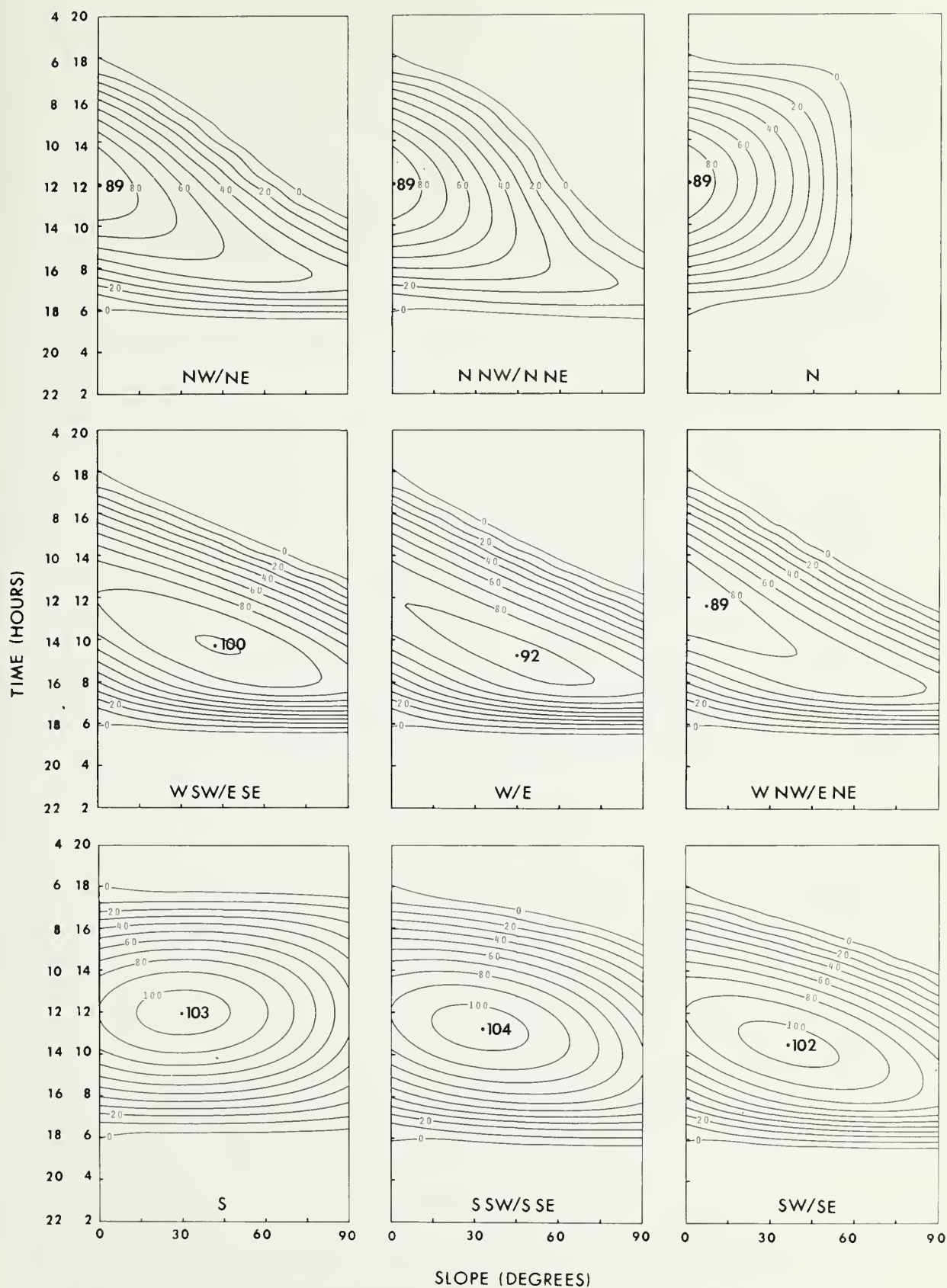


Figure 19.—Isograms of hourly values of direct solar radiation for various slopes at 30 degrees north latitude on March 21 and September 23. For westerly exposures, the time is read from top to bottom (left time axis); for easterly exposures, the time is read from bottom to top (right time axis).



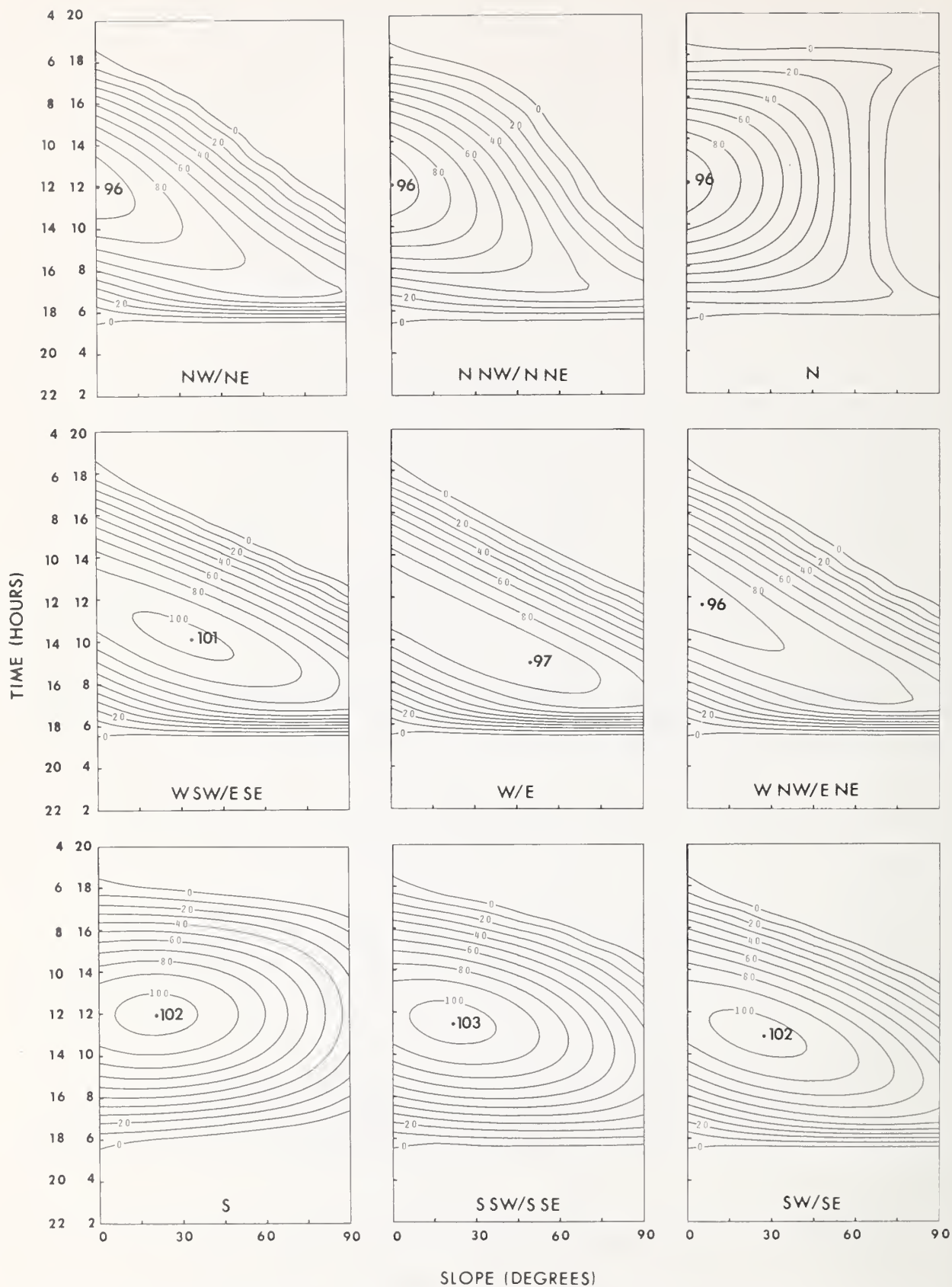


Figure 20.—Isograms of hourly values of direct solar radiation for various slopes at 30 degrees north latitude on April 16 and August 28. For westerly exposures, the time is read from top to bottom (left time axis); for easterly exposures, the time is read from bottom to top (right time axis).

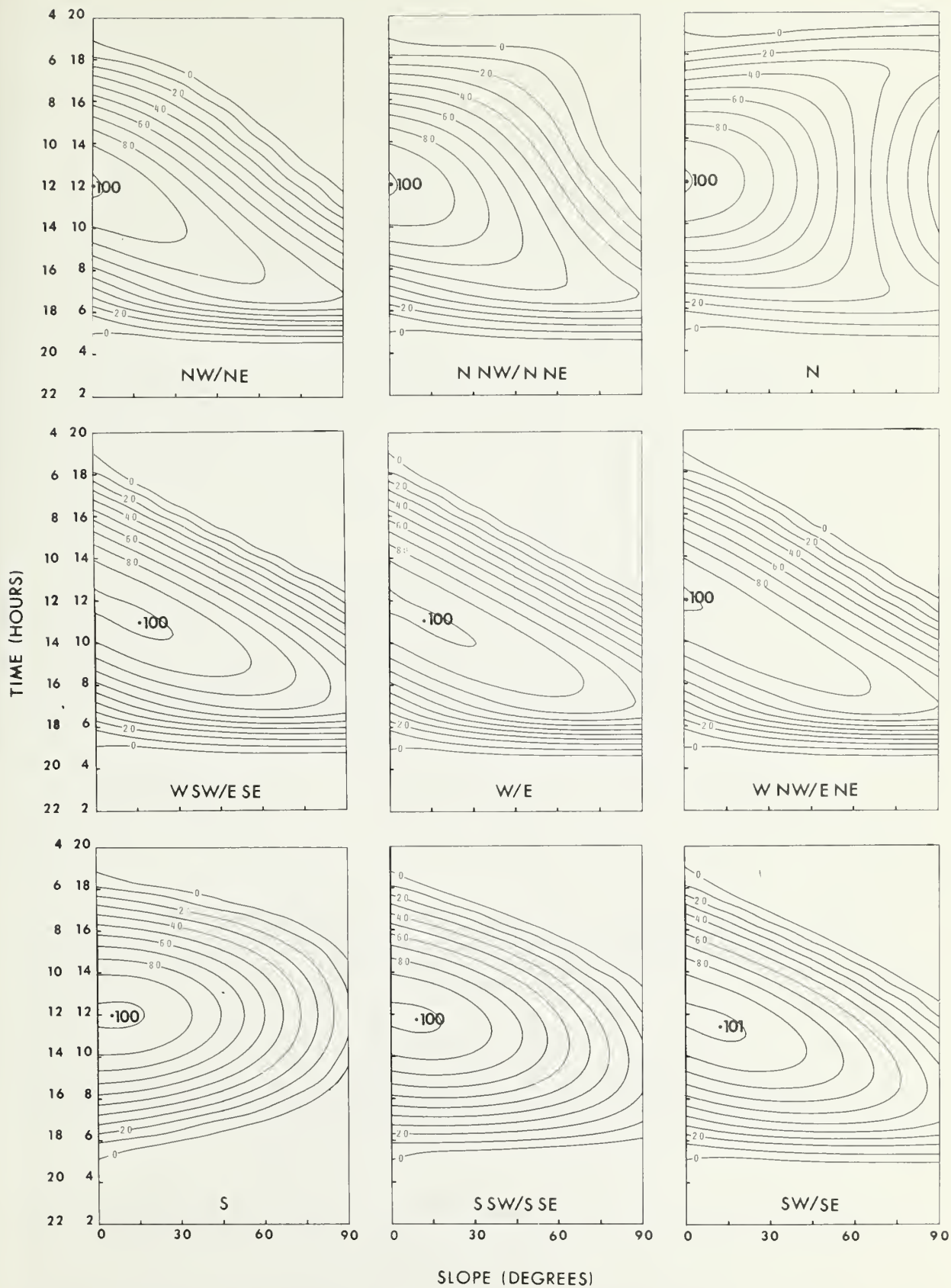


Figure 21.—Isograms of hourly values of direct solar radiation for various slopes at 30 degrees north latitude on June 22. For westerly exposures, the time is read from top to bottom (left time axis); for easterly exposures, the time is read from bottom to top (right time axis).

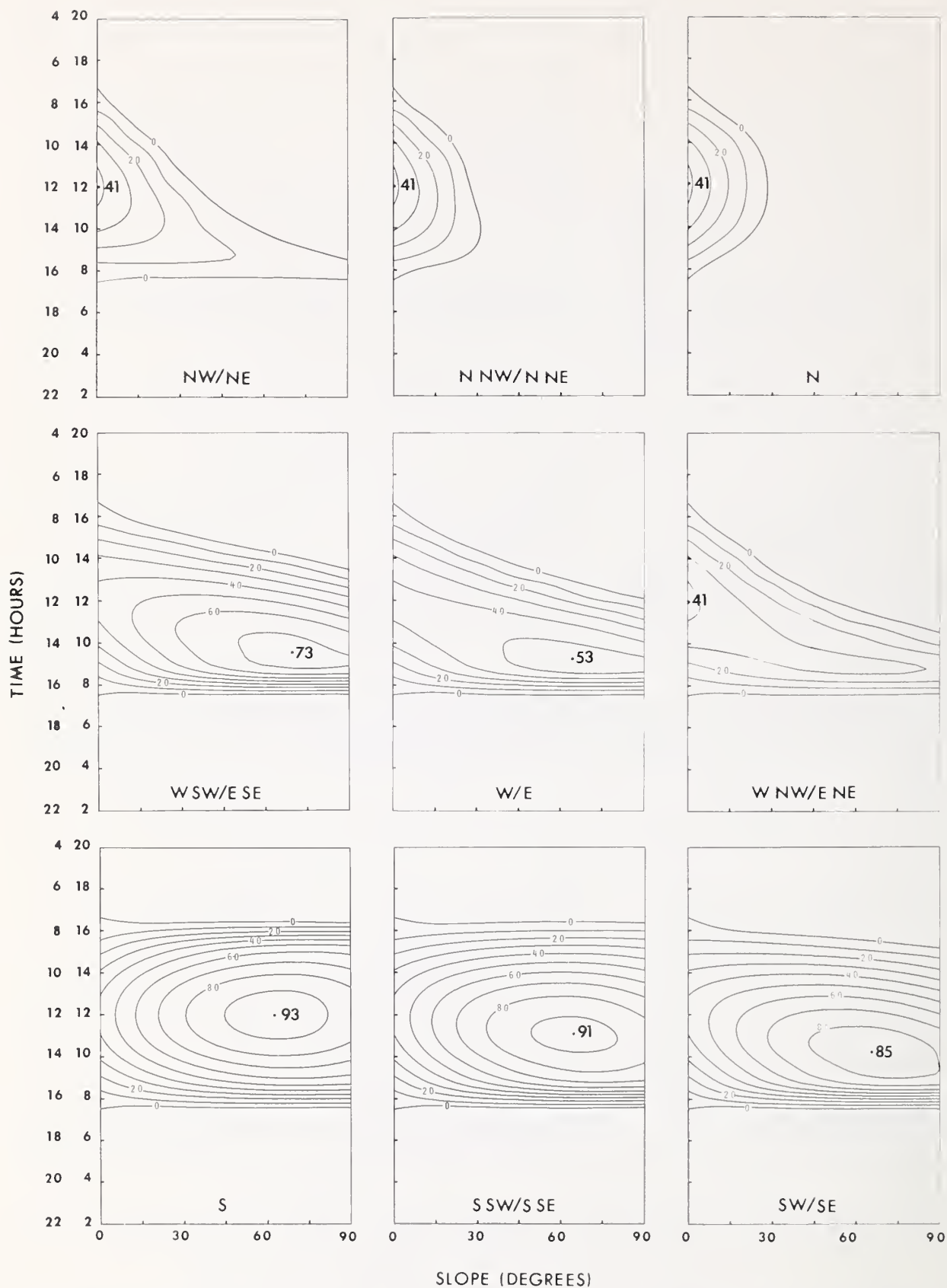


Figure 22.—Isograms of hourly values of direct solar radiation for various slopes at 40 degrees north latitude on December 22. For westerly exposures, the time is read from top to bottom (left time axis); for easterly exposures, the time is read from bottom to top (right time axis).



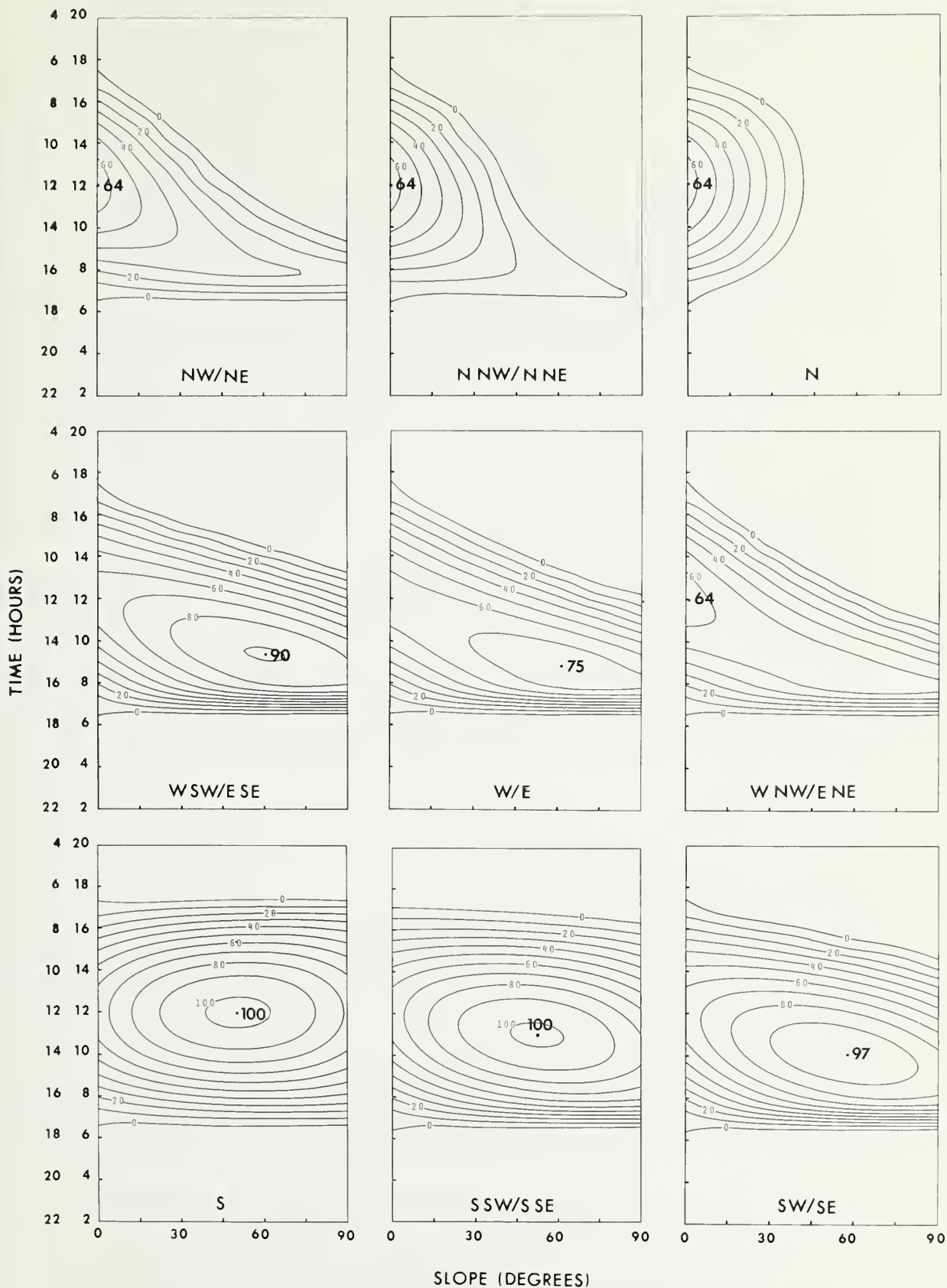


Figure 23.—Isograms of hourly values of direct solar radiation for various slopes at 40 degrees north latitude on February 23 and October 20. For westerly exposures, the time is read from top to bottom (left time axis); for easterly exposures, the time is read from bottom to top (right time axis).

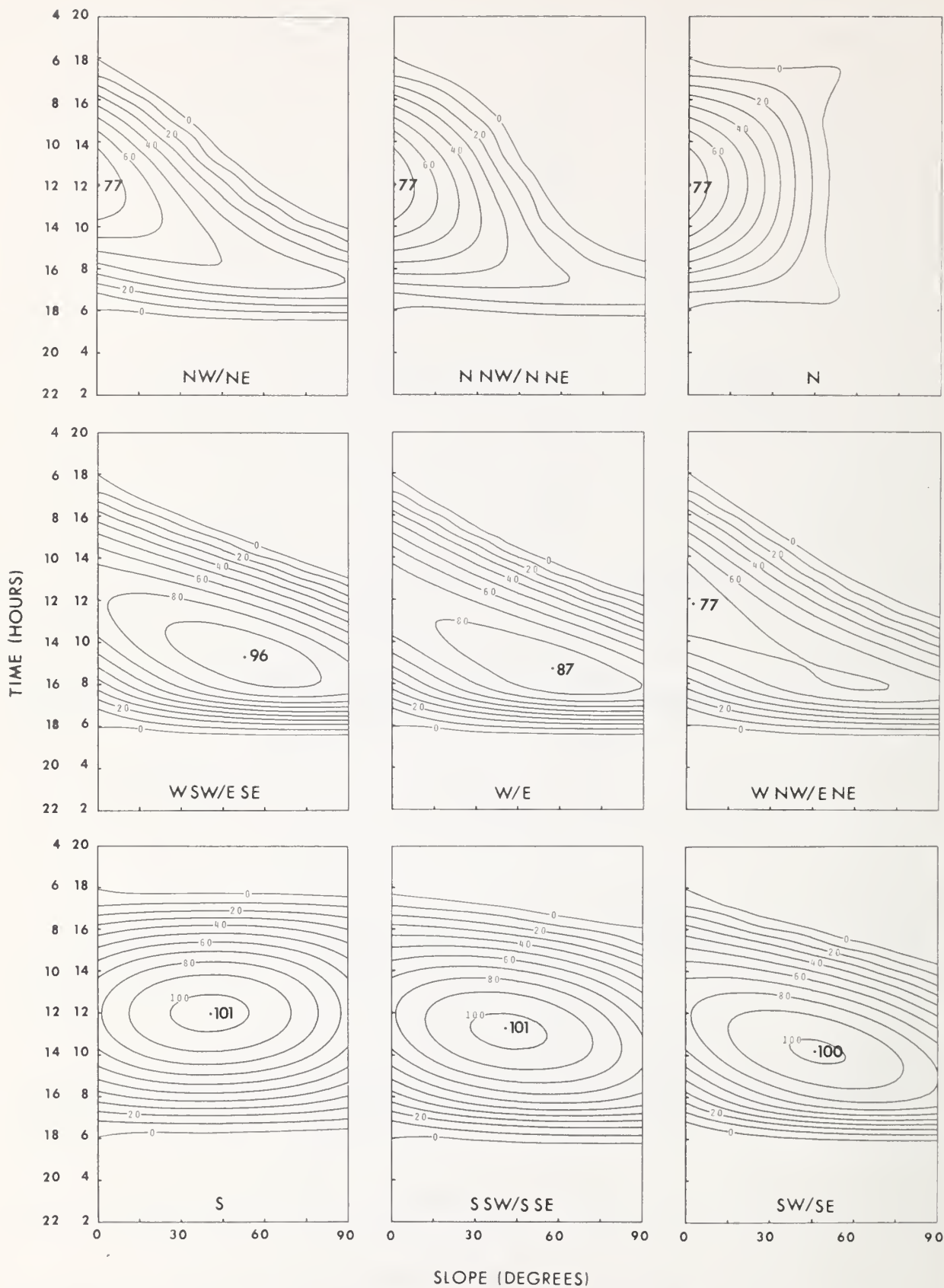


Figure 24.—Isograms of hourly values of direct solar radiation for various slopes at 40 degrees north latitude on March 21 and September 23. For westerly exposures, the time is read from top to bottom (left time axis); for easterly exposures, the time is read from bottom to top (right time axis).

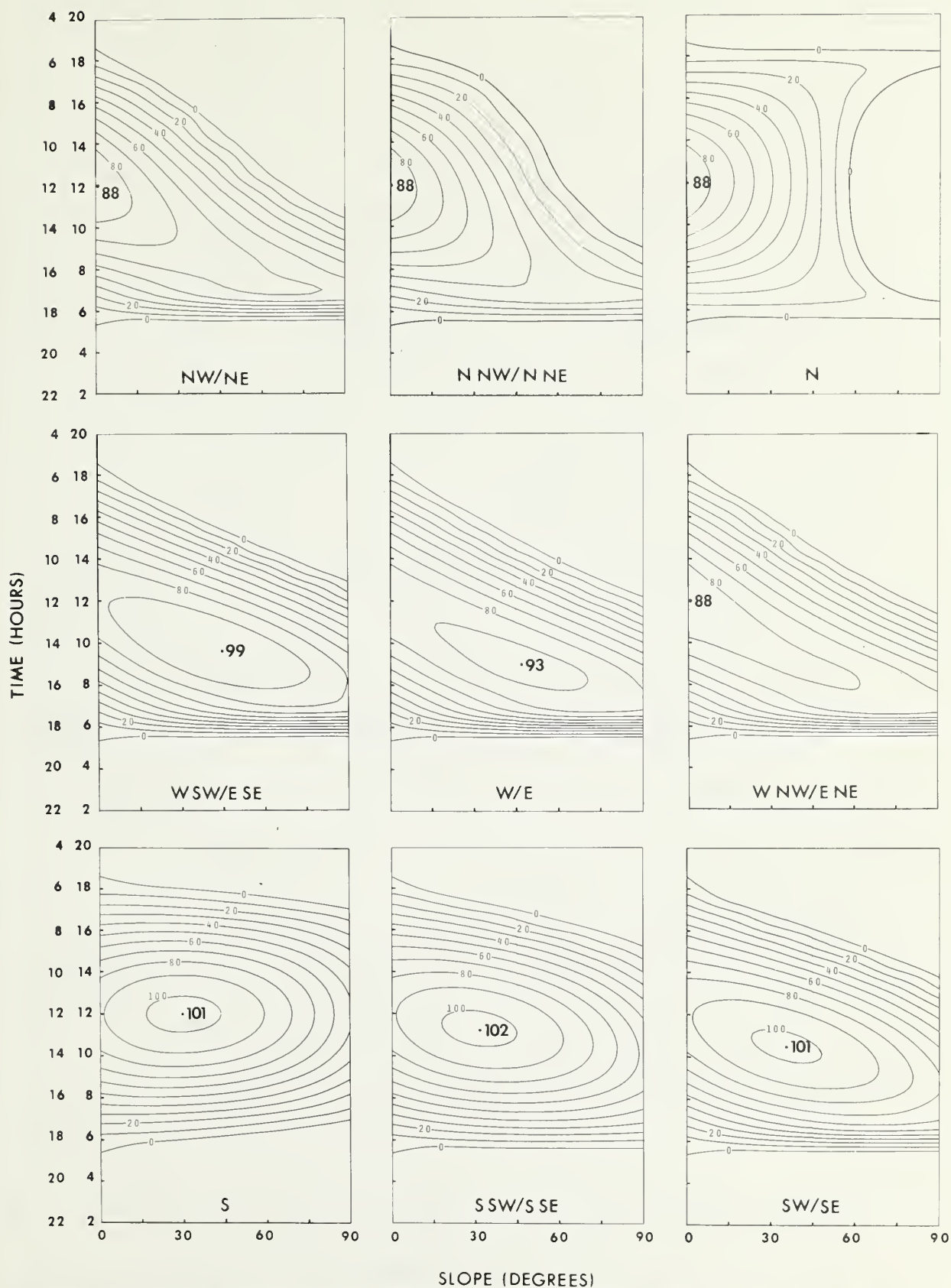


Figure 25.—Isograms of hourly values of direct solar radiation for various slopes at 40 degrees north latitude on April 16 and August 28. For westerly exposures, the time is read from top to bottom (left time axis); for easterly exposures, the time is read from bottom to top (right time axis).

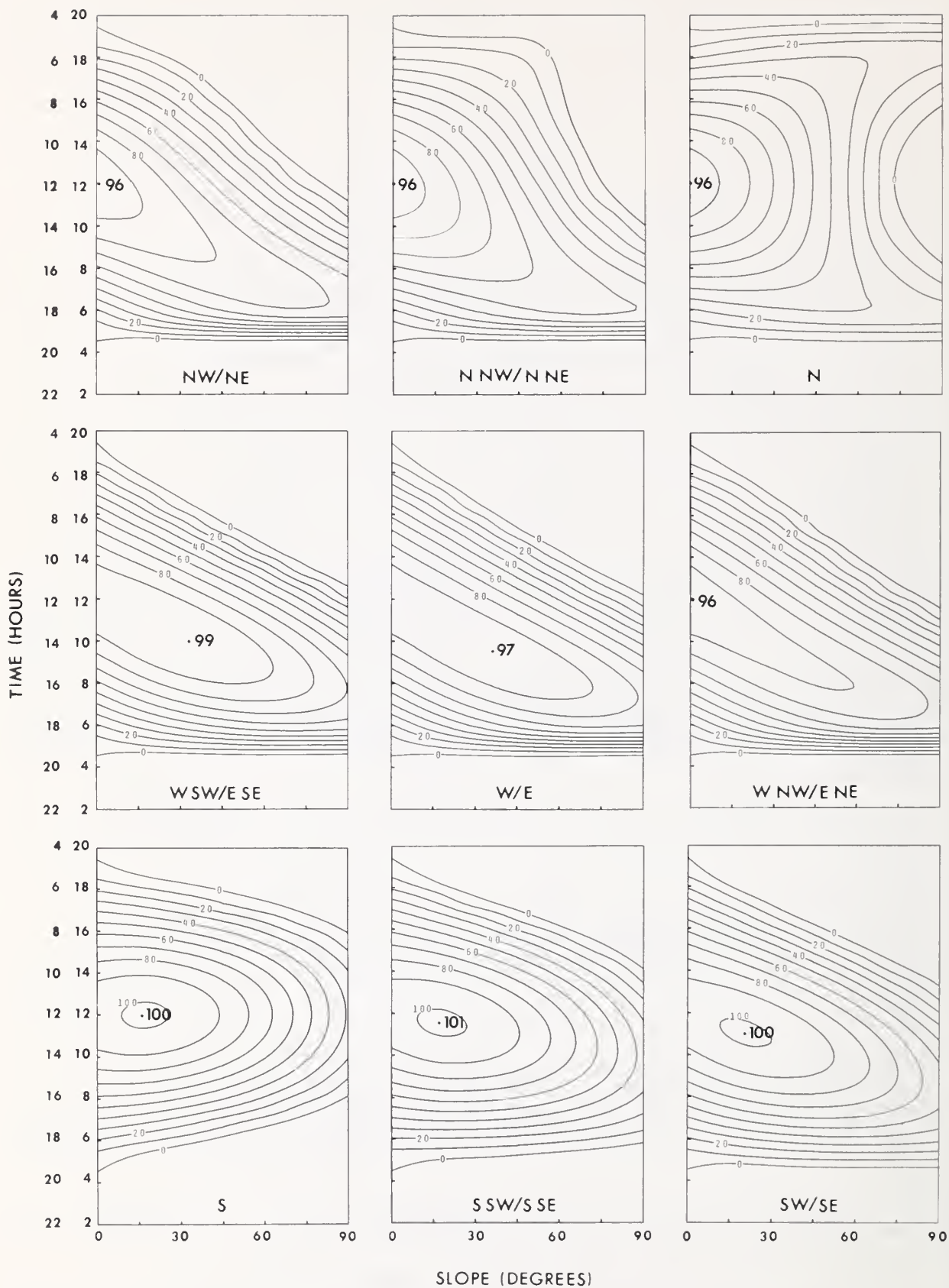


Figure 26.—Isograms of hourly values of direct solar radiation for various slopes at 40 degrees north latitude on June 22. For westerly exposures, the time is read from top to bottom (left time axis); for easterly exposures, the time is read from bottom to top (right time axis).

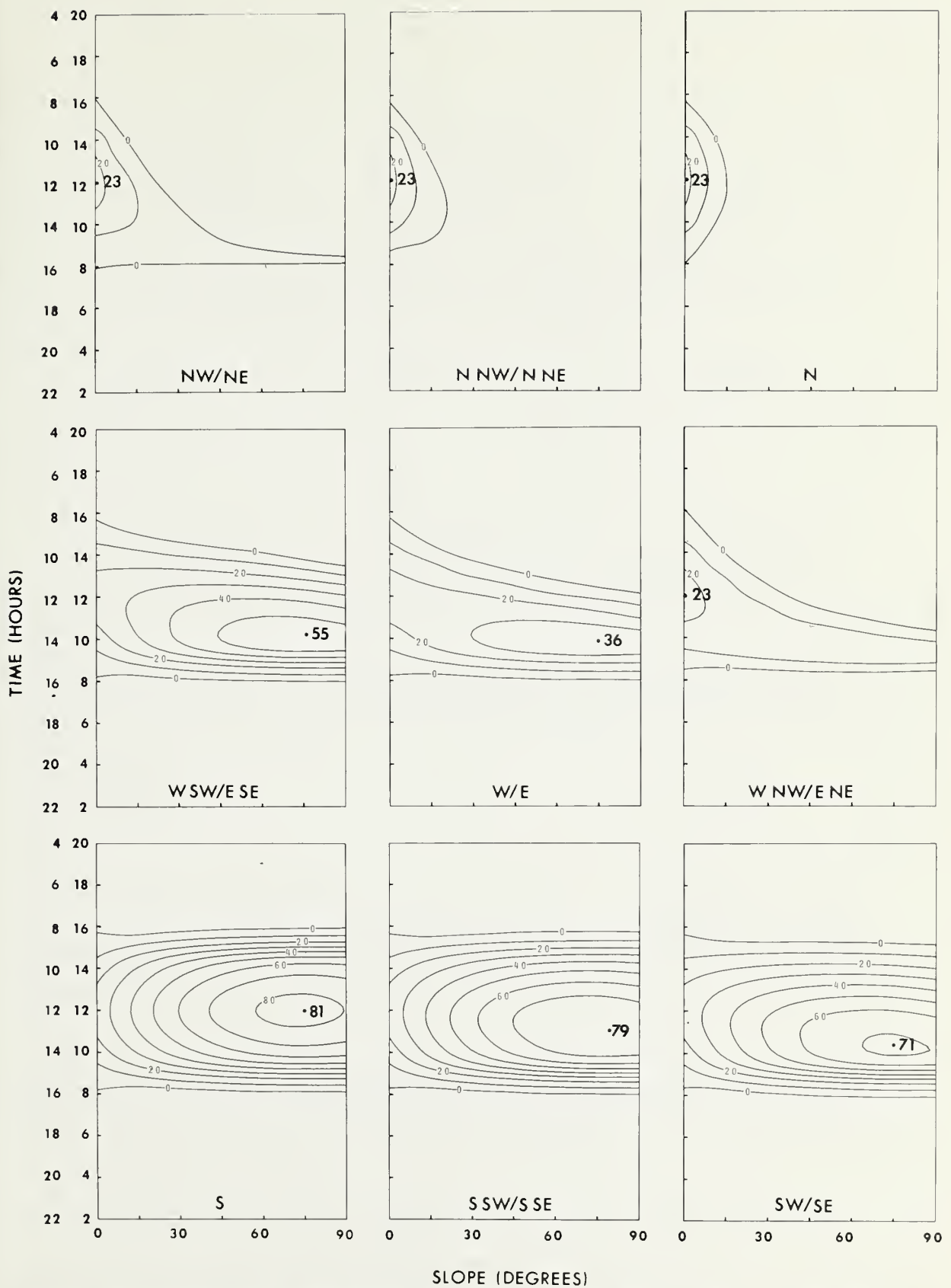


Figure 27.—Isograms of hourly values of direct solar radiation for various slopes at 50 degrees north latitude on December 22. For westerly exposures, the time is read from top to bottom (left time axis); for easterly exposures, the time is read from bottom to top (right time axis).



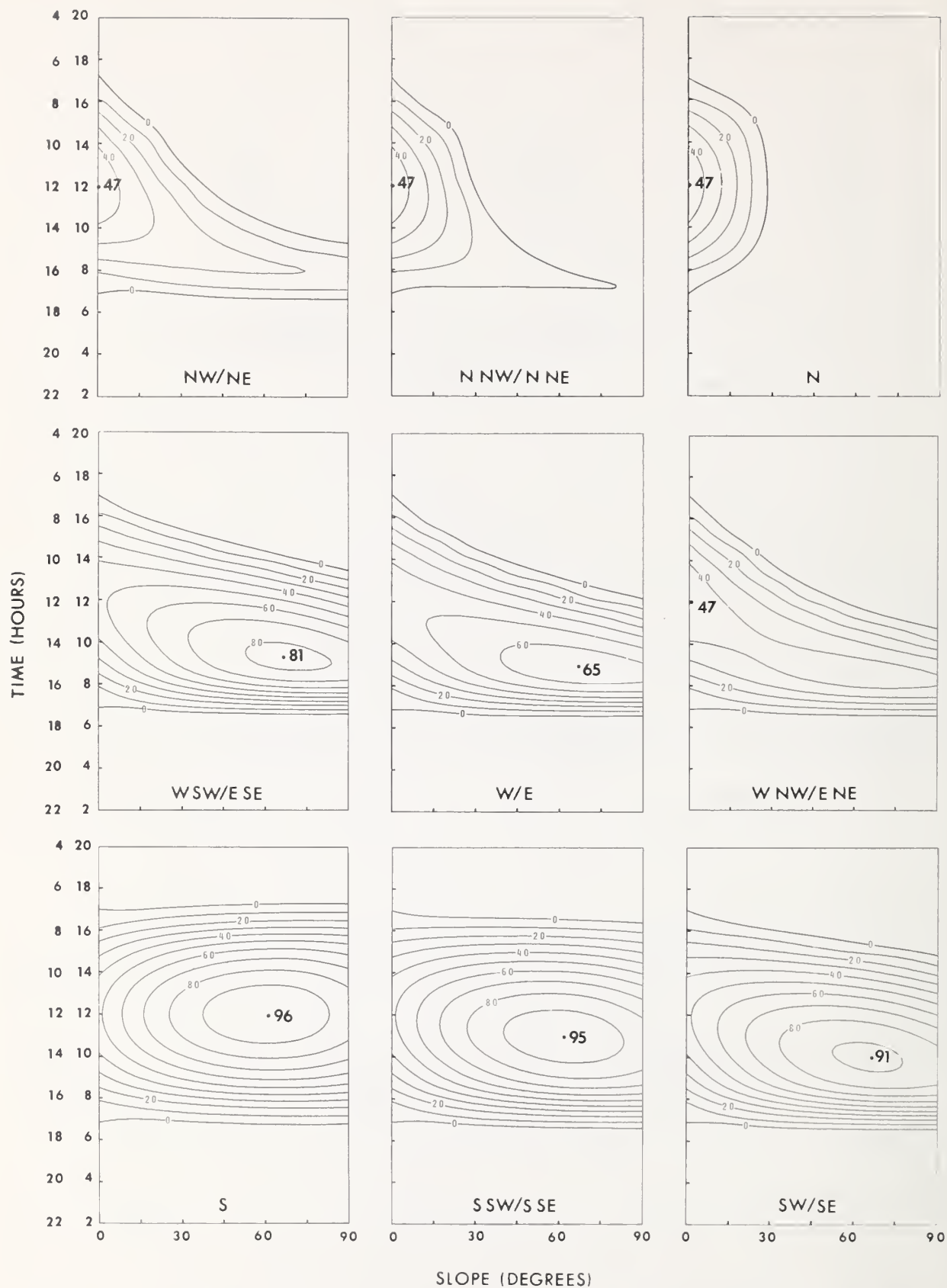


Figure 28.—Isograms of hourly values of direct solar radiation for various slopes at 50 degrees north latitude on February 23 and October 20. For westerly exposures, the time is read from top to bottom (left time axis); for easterly exposures, the time is read from bottom to top (right time axis).

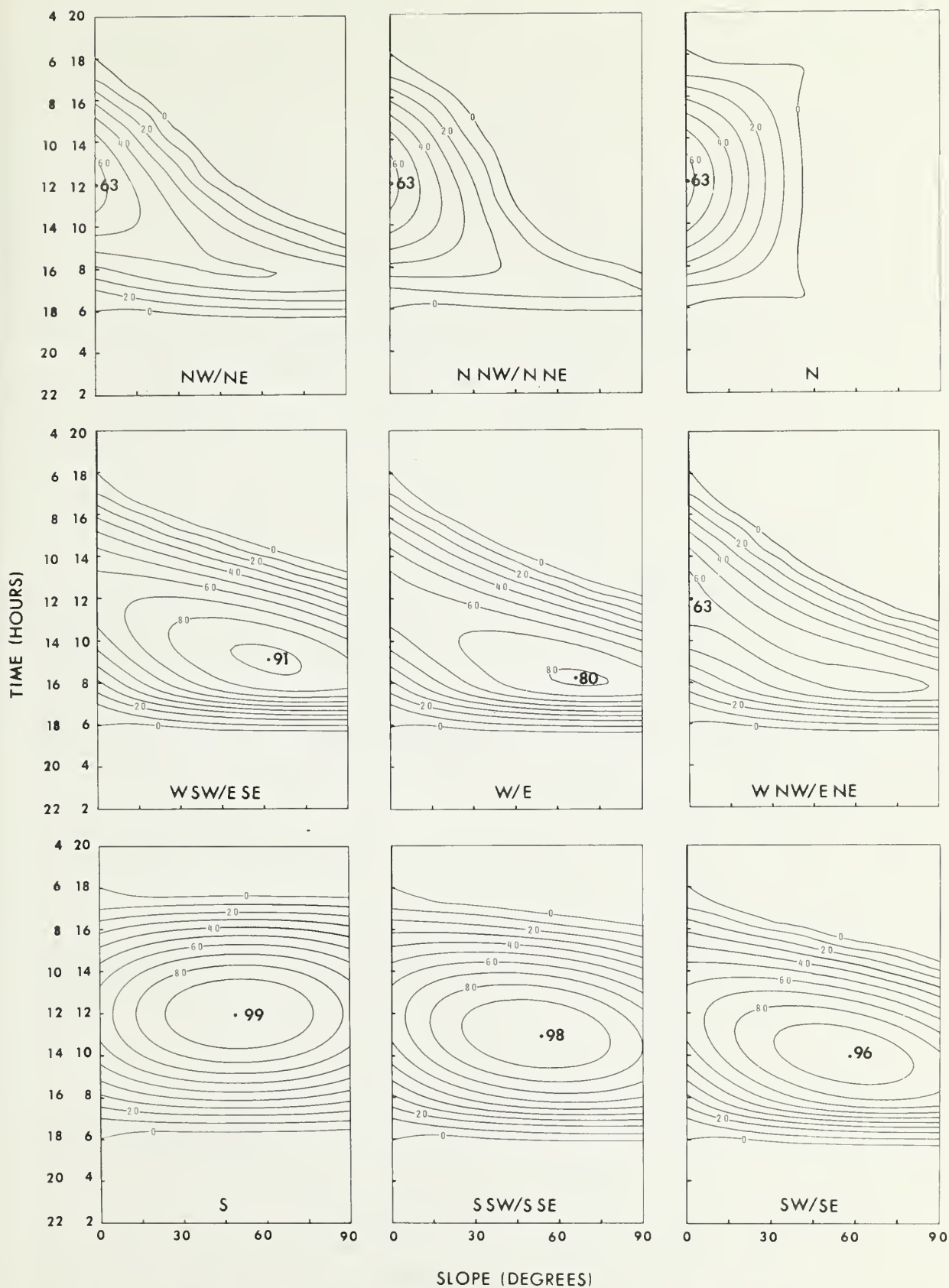


Figure 29.—Isograms of hourly values of direct solar radiation for various slopes at 50 degrees north latitude on March 21 and September 23. For westerly exposures, the time is read from top to bottom (left time axis); for easterly exposures, the time is read from bottom to top (right time axis).

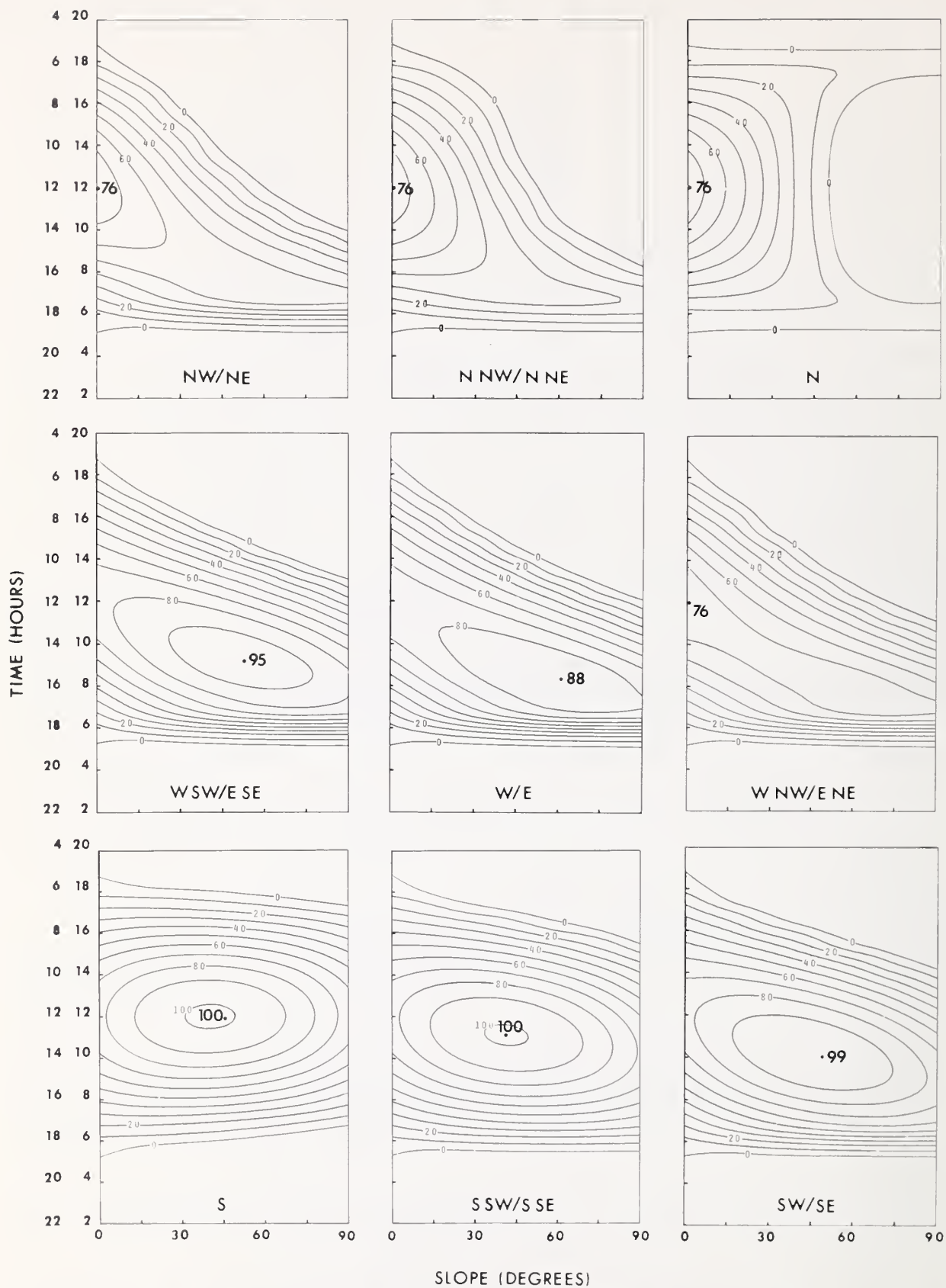


Figure 30.—Isograms of hourly values of direct solar radiation for various slopes at 50 degrees north latitude on April 16 and August 28. For westerly exposures, the time is read from top to bottom (left time axis); for easterly exposures, the time is read from bottom to top (right time axis).

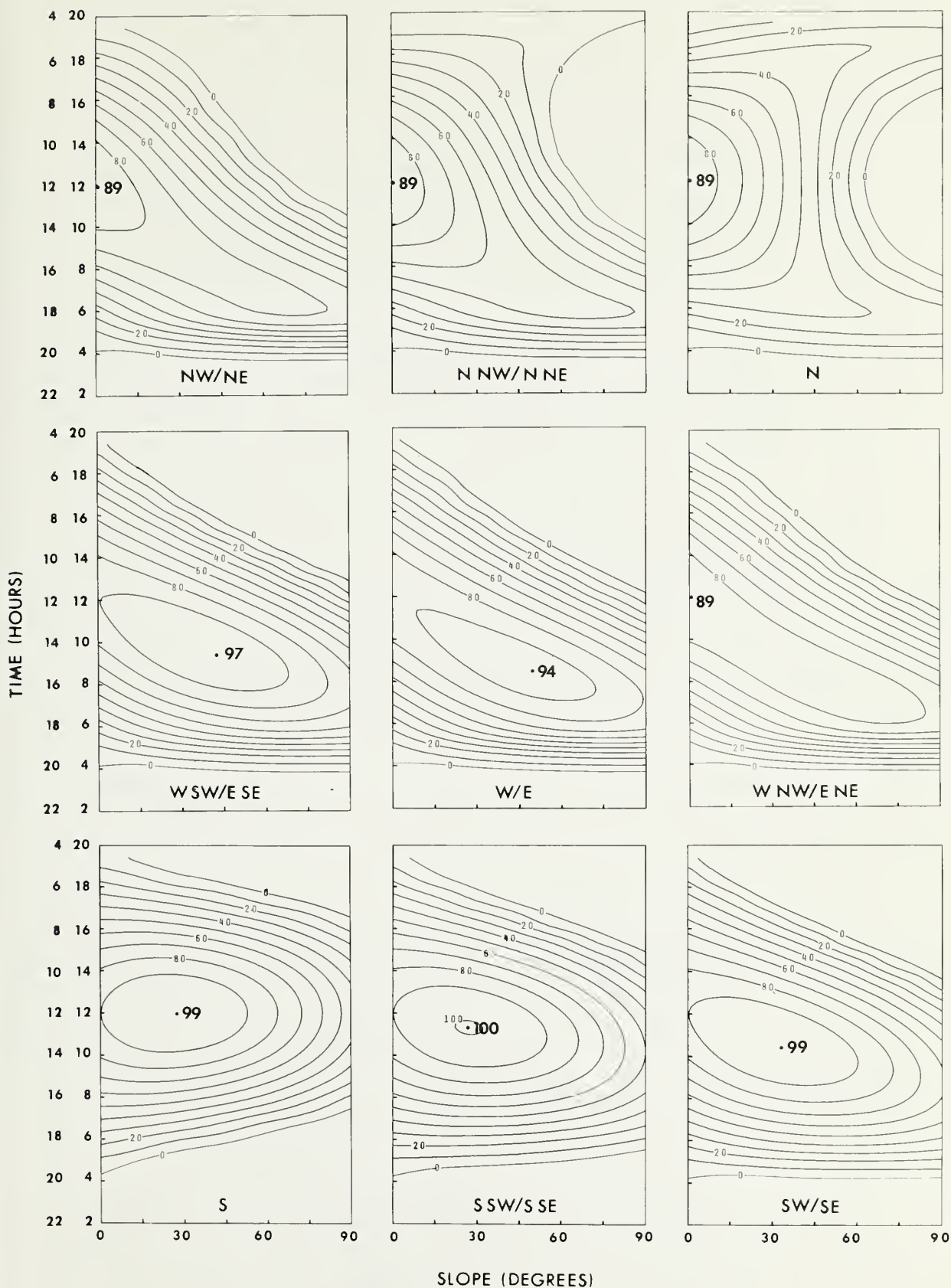


Figure 31.—Isograms of hourly values of direct solar radiation for various slopes at 50 degrees north latitude on June 22. For westerly exposures, the time is read from top to bottom (left time axis); for easterly exposures, the time is read from bottom to top (right time axis).

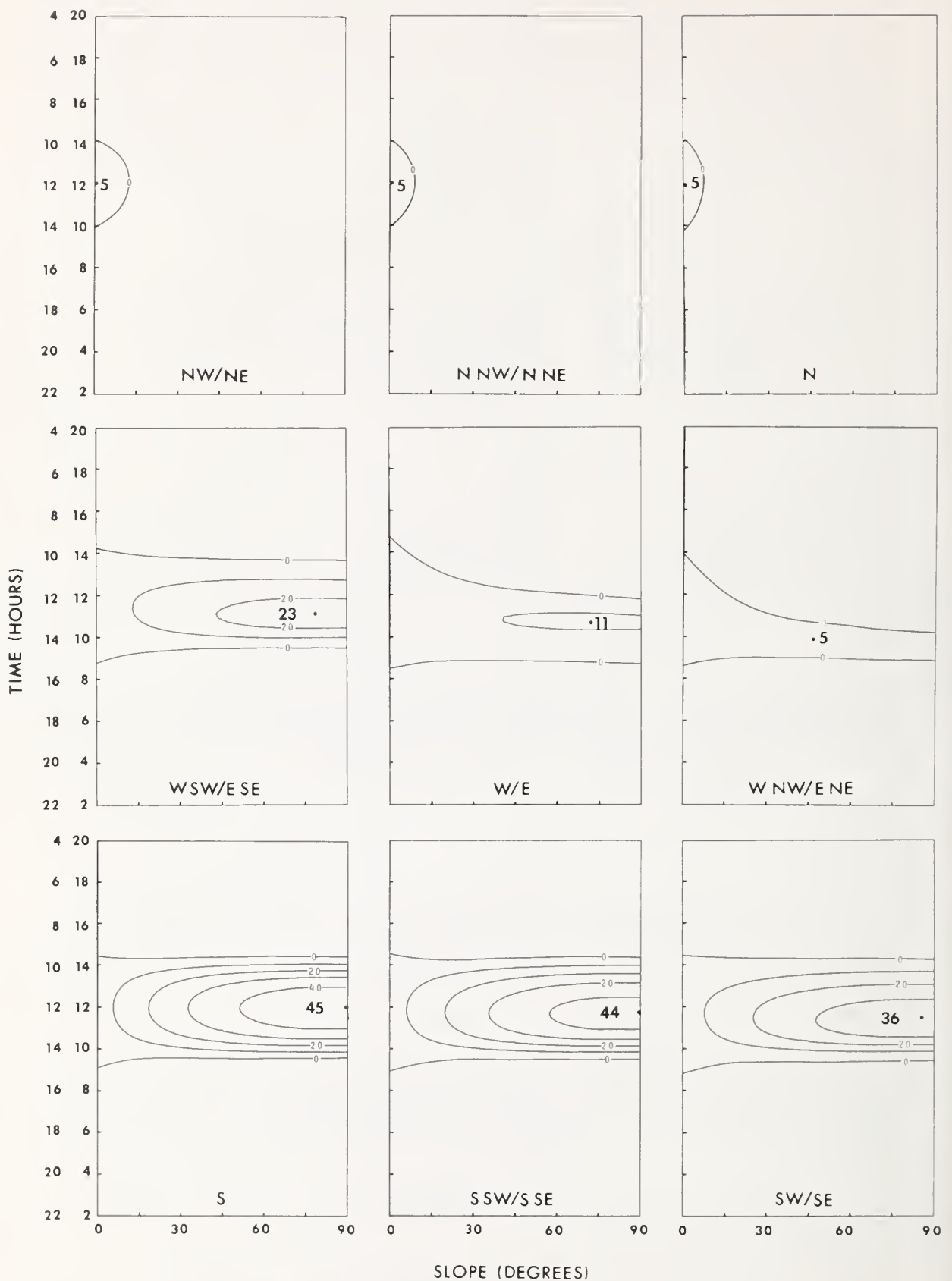


Figure 32.—Isograms of hourly values of direct solar radiation for various slopes at 60 degrees north latitude on December 22. For westerly exposures, the time is read from top to bottom (left time axis); for easterly exposures, the time is read from bottom to top (right time axis).



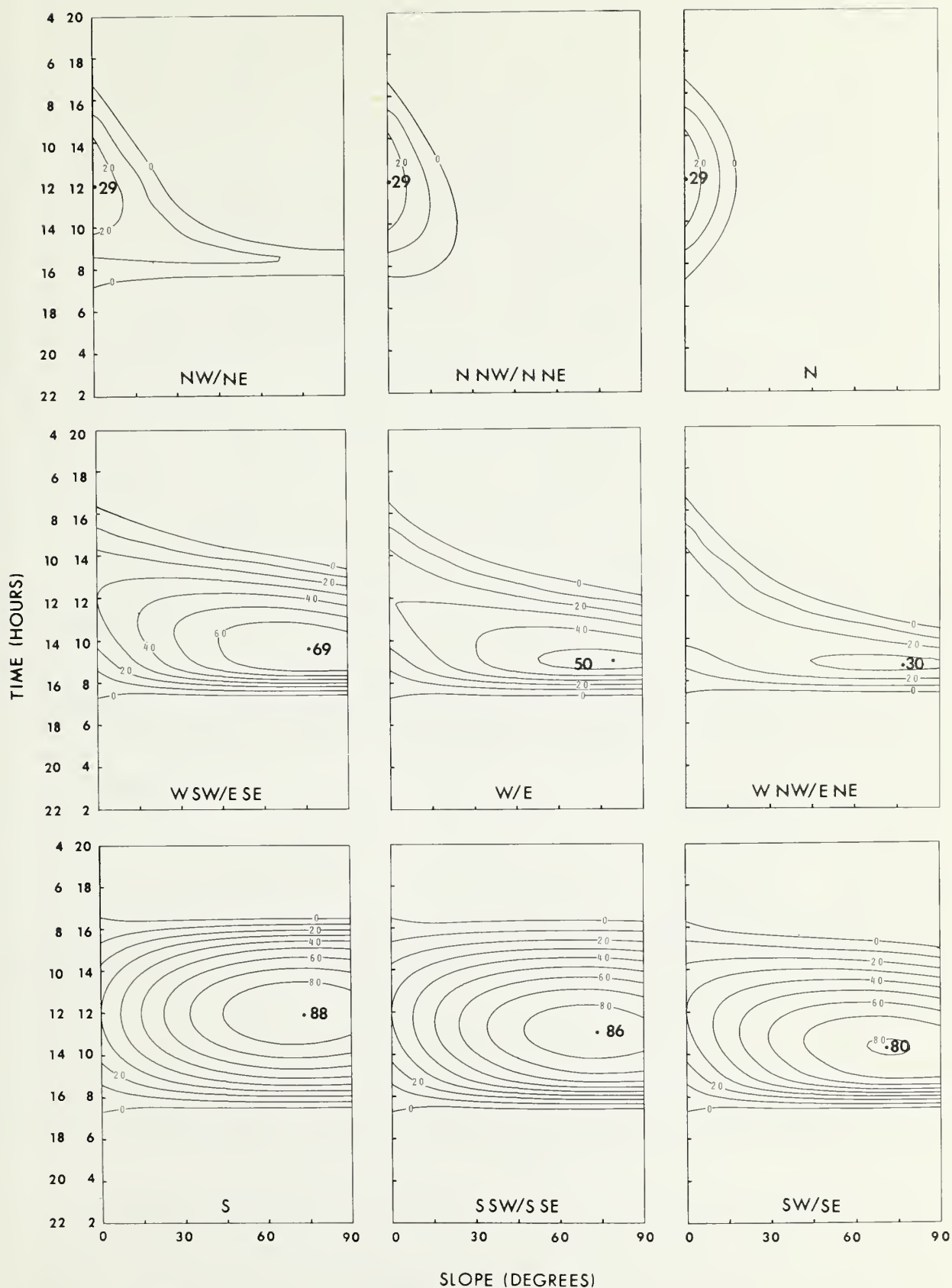


Figure 33.—Isograms of hourly values of direct solar radiation for various slopes at 60 degrees north latitude on February 23 and October 20. For westerly exposures, the time is read from top to bottom (left time axis); for easterly exposures, the time is read from bottom to top (right time axis).

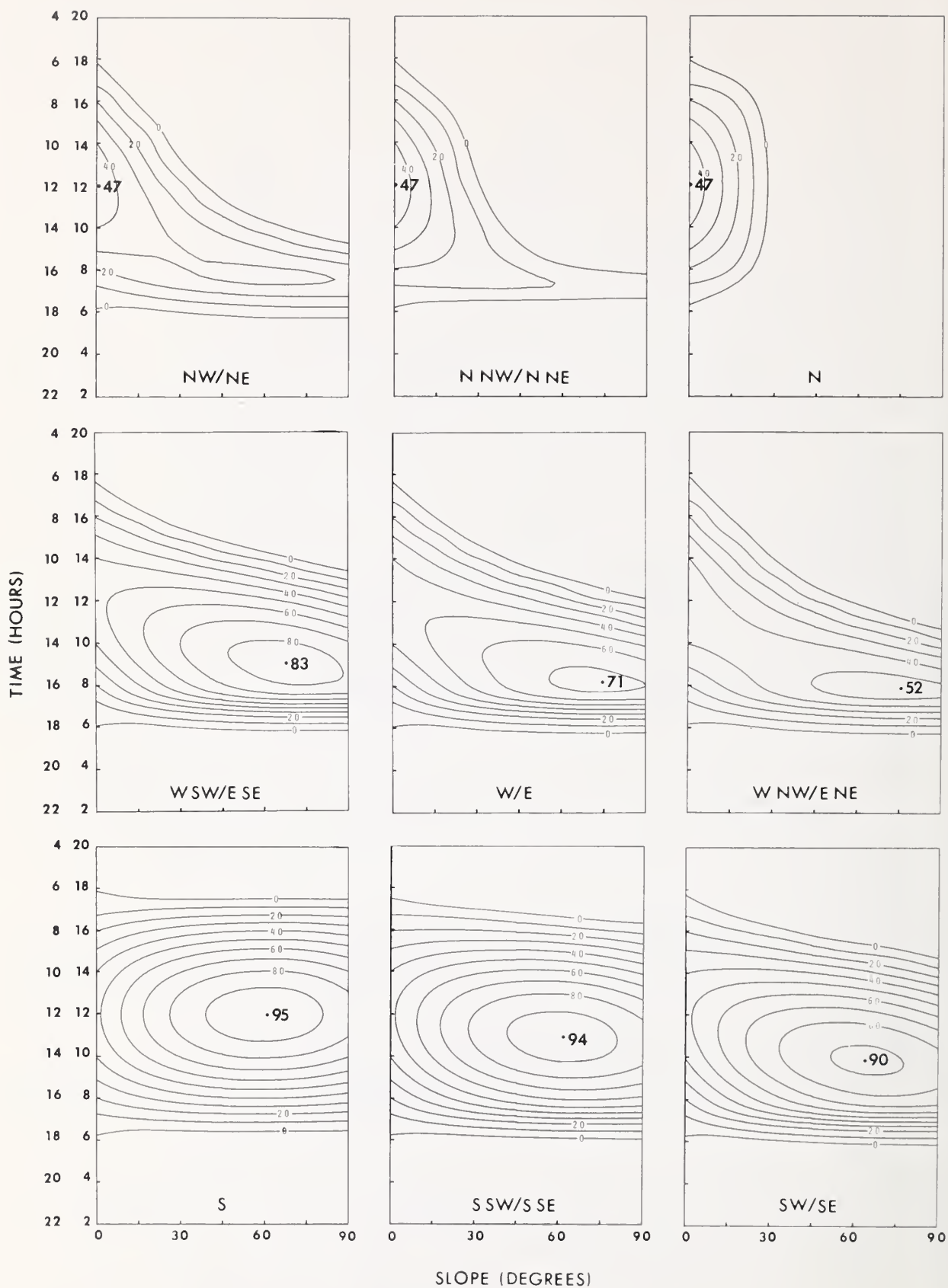


Figure 34.—Isograms of hourly values of direct solar radiation for various slopes at 60 degrees north latitude on March 21 and September 23. For westerly exposures, the time is read from top to bottom (left time axis); for easterly exposures, the time is read from bottom to top (right time axis).

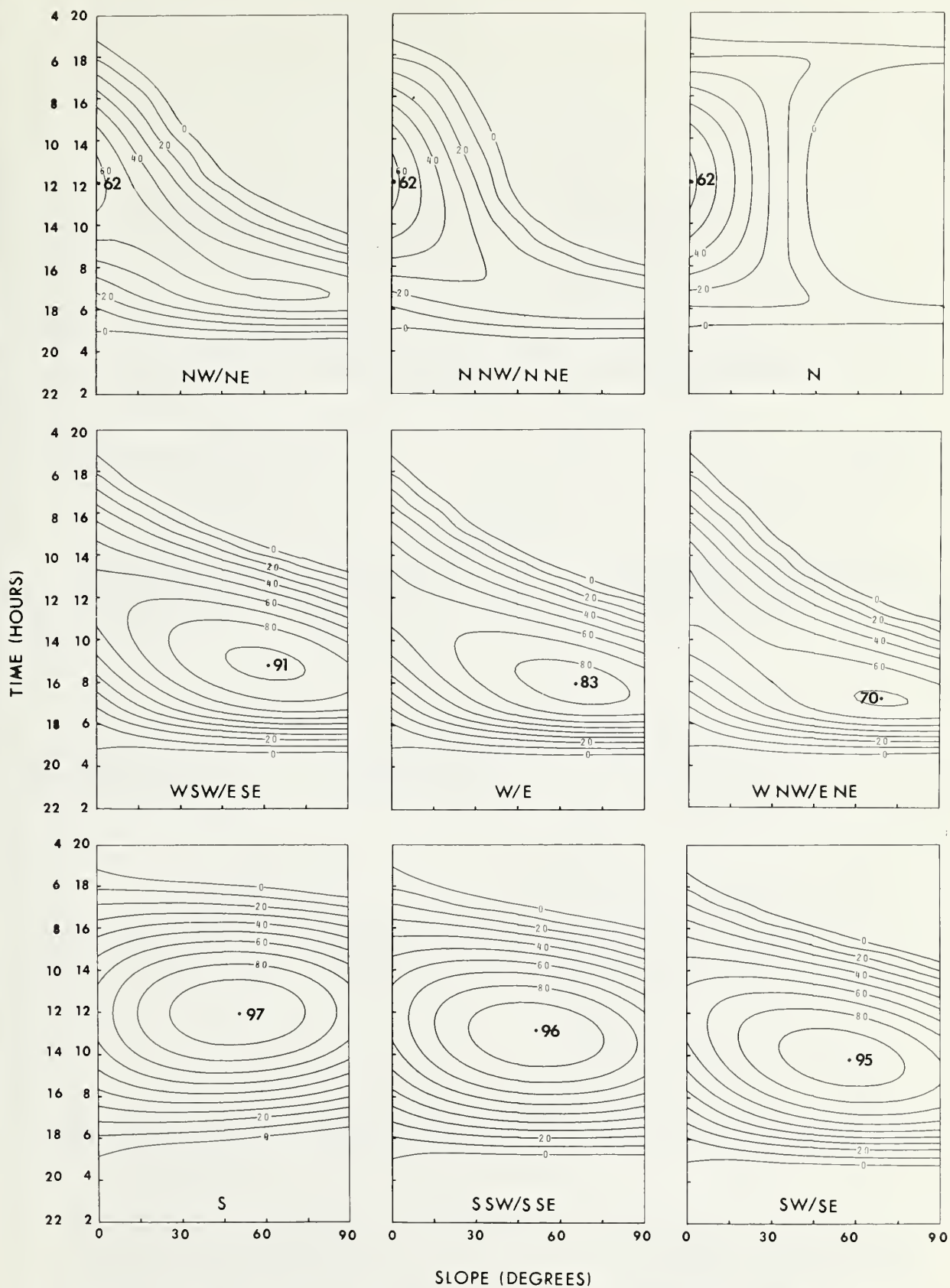


Figure 35.—Isograms of hourly values of direct solar radiation for various slopes at 60 degrees north latitude on April 16 and August 28. For westerly exposures, the time is read from top to bottom (left time axis); for easterly exposures, the time is read from bottom to top (right time axis).

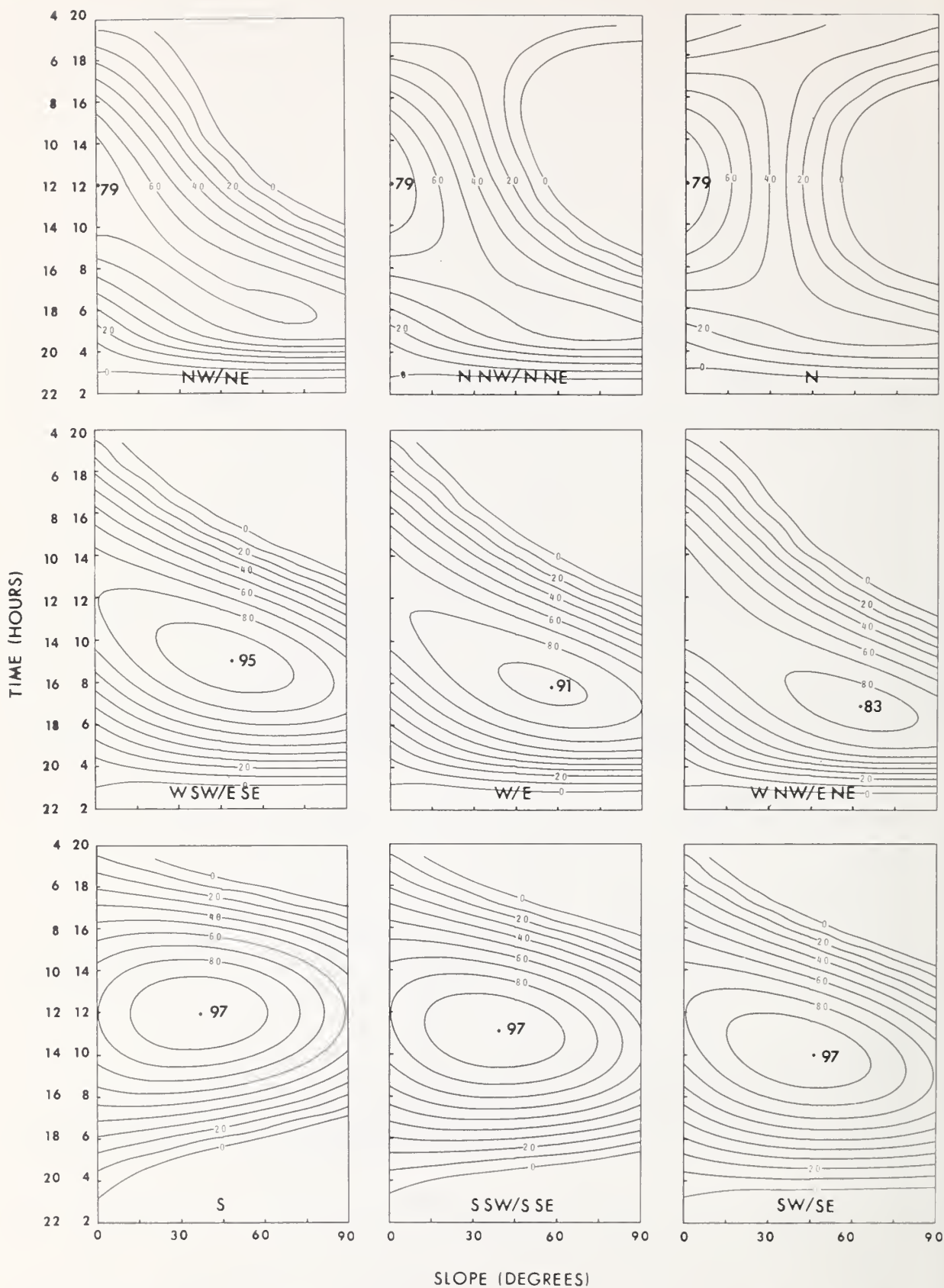


Figure 36.—Isograms of hourly values of direct solar radiation for various slopes at 60 degrees north latitude on June 22. For westerly exposures, the time is read from top to bottom (left time axis); for easterly exposures, the time is read from bottom to top (right time axis).

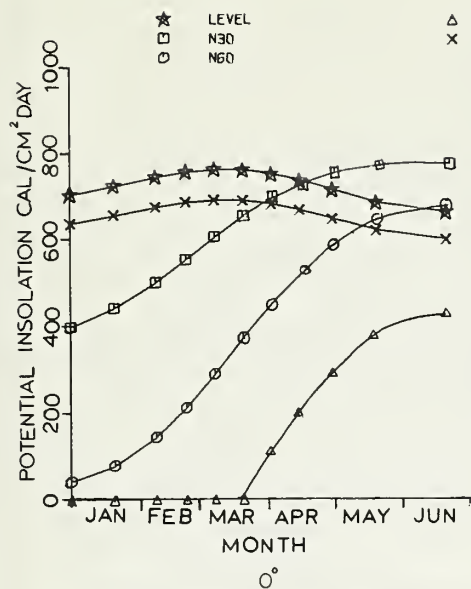


Figure 37.—Isograms of daily values of direct solar radiation on level, north 30-, north 60-, north 90-, and east 30-degree slopes at 0 degrees north latitude.

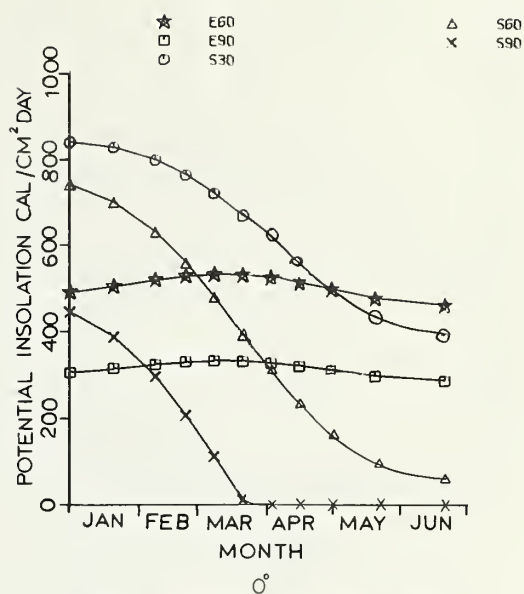


Figure 38.—Isograms of daily values of direct solar radiation on east 60-, east 90-, south 30-, south 60-, and south 90-degree slopes at 0 degrees north latitude.

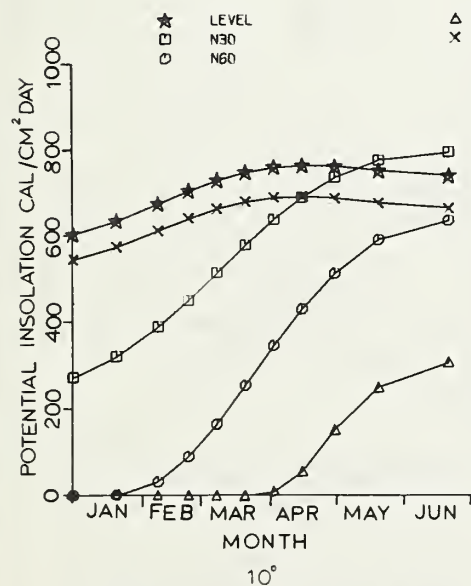


Figure 39.—Isograms of daily values of direct solar radiation on level, north 30-, north 60-, north 90-, and east 30-degree slopes at 10 degrees north latitude.

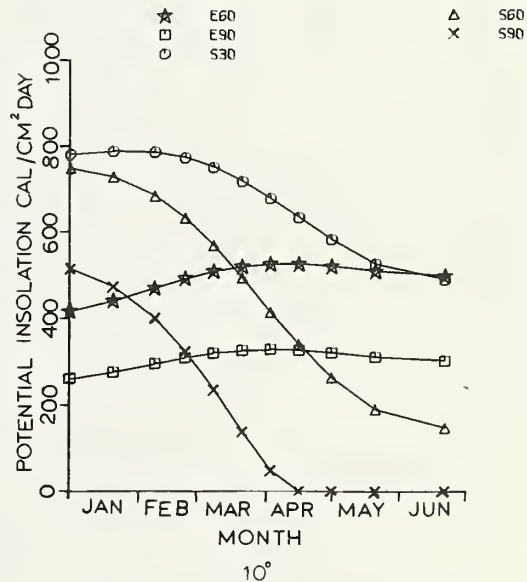


Figure 40.—Isograms of daily values of direct solar radiation on east 60-, east 90-, south 30-, south 60-, and south 90-degree slopes at 10 degrees north latitude.



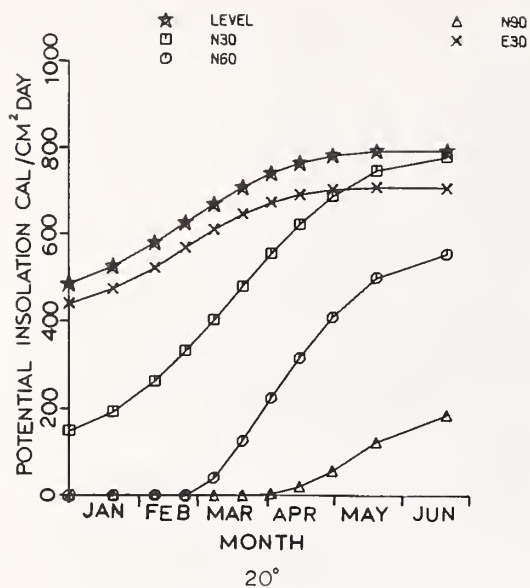


Figure 41.—Isograms of daily values of direct solar radiation on level, north 30-, north 60-, north 90-, and east 30-degree slopes at 20 degrees north latitude.

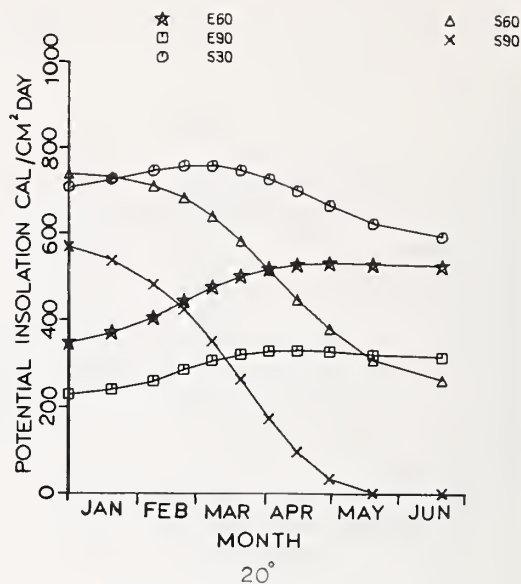


Figure 42.—Isograms of daily values of direct solar radiation on east 60-, east 90-, south 30-, south 60-, and south 90-degree slopes at 20 degrees north latitude.

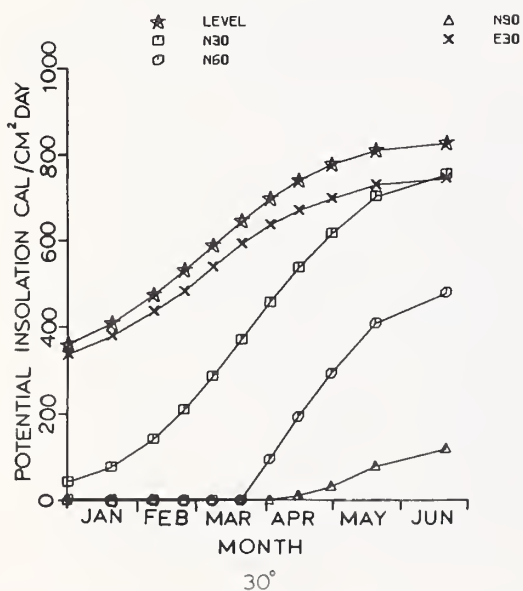


Figure 43.—Isograms of daily values of direct solar radiation on level, north 30-, north 60-, north 90-, and east 30-degree slopes at 30 degrees north latitude.

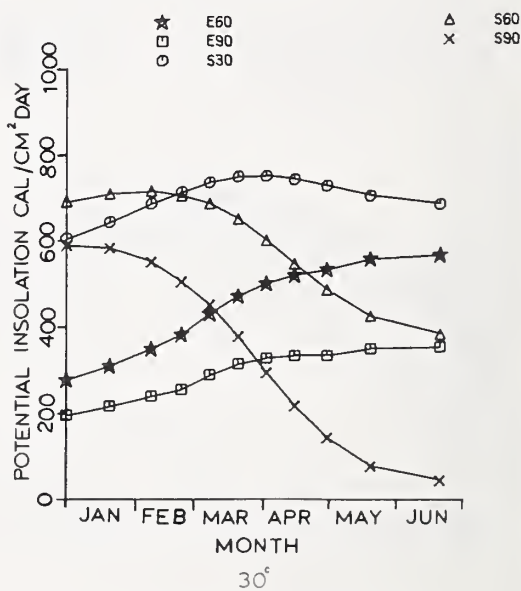


Figure 44.—Isograms of daily values of direct solar radiation on east 60-, east 90-, south 30-, south 60-, and south 90-degree slopes at 30 degrees north latitude.

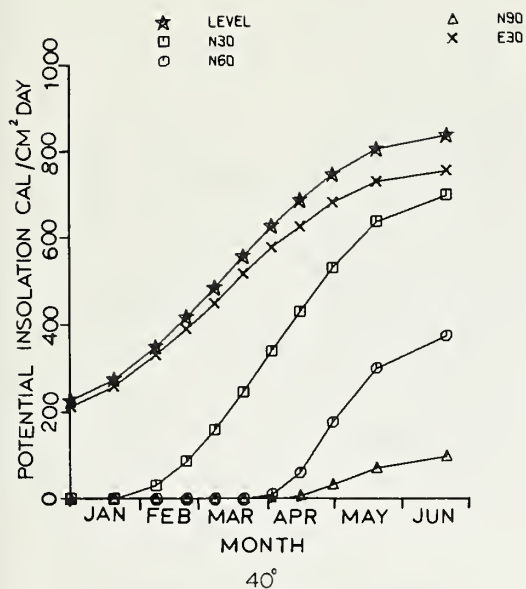


Figure 45.—Isograms of daily values of direct solar radiation on level, north 30-, north 60-, north 90-, and east 30-degree slopes at 40 degrees north latitude.

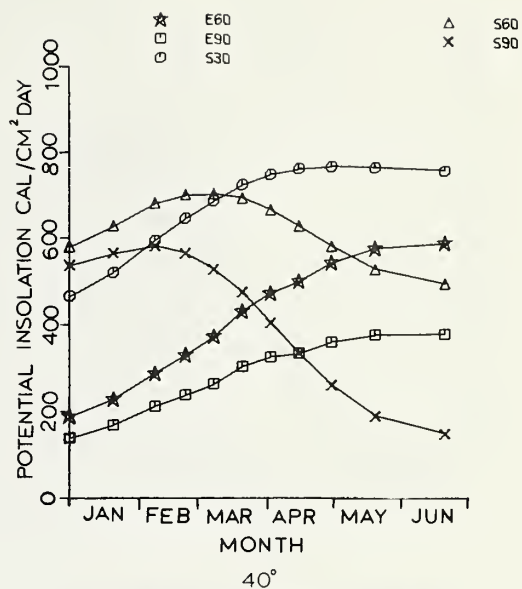


Figure 46.—Isograms of daily values of direct solar radiation on east 60-, east 90-, south 30-, south 60-, and south 90-degree slopes at 40 degrees north latitude.

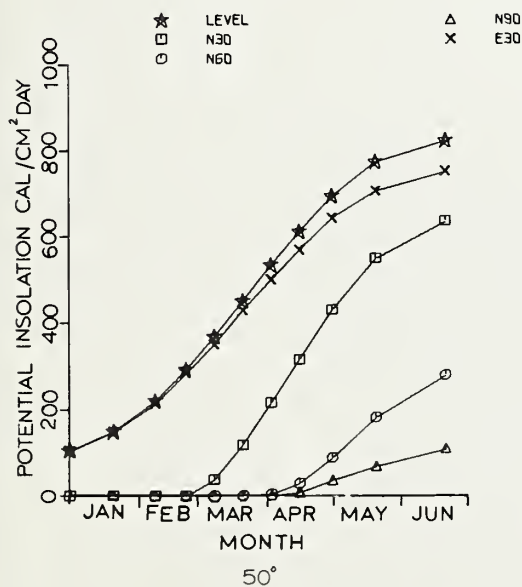


Figure 47.—Isograms of daily values of direct solar radiation on level, north 30-, north 60-, north 90-, and east 30-degree slopes at 50 degrees north latitude.

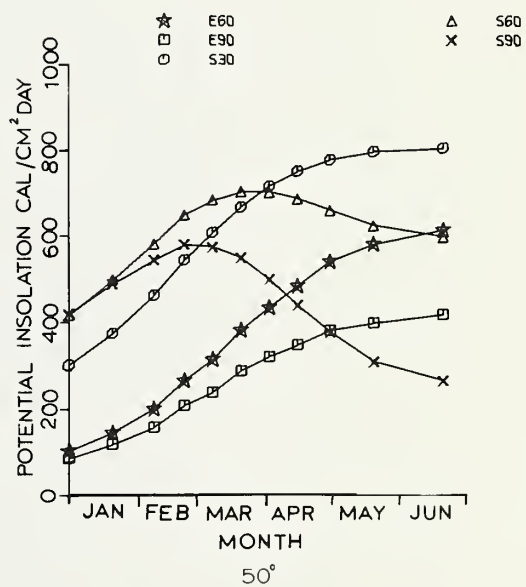


Figure 48.—Isograms of daily values of direct solar radiation on east 60-, east 90-, south 30-, south 60-, and south 90-degree slopes at 50 degrees north latitude.

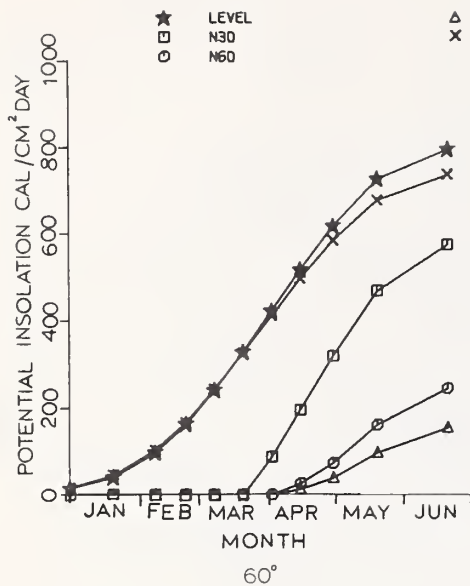


Figure 49.—Isograms of daily values of direct solar radiation on level, north 30-, north 60-, north 90-, and east 30-degree slopes at 60 degrees north latitude.

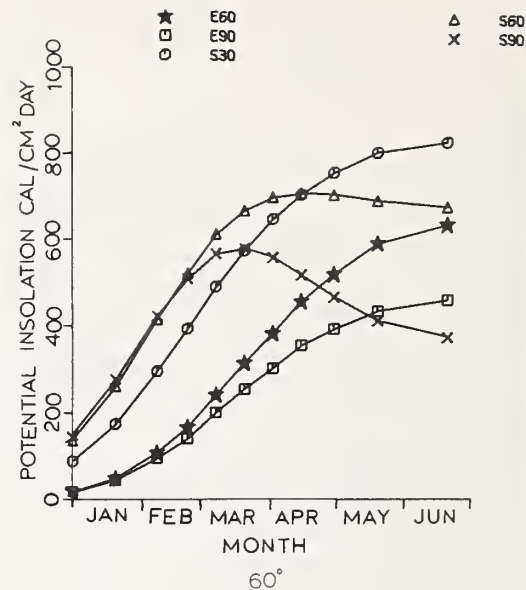


Figure 50.—Isograms of daily values of direct solar radiation on east 60-, east 90-, south 30-, south 60-, and south 90-degree slopes at 60 degrees north latitude.

0°

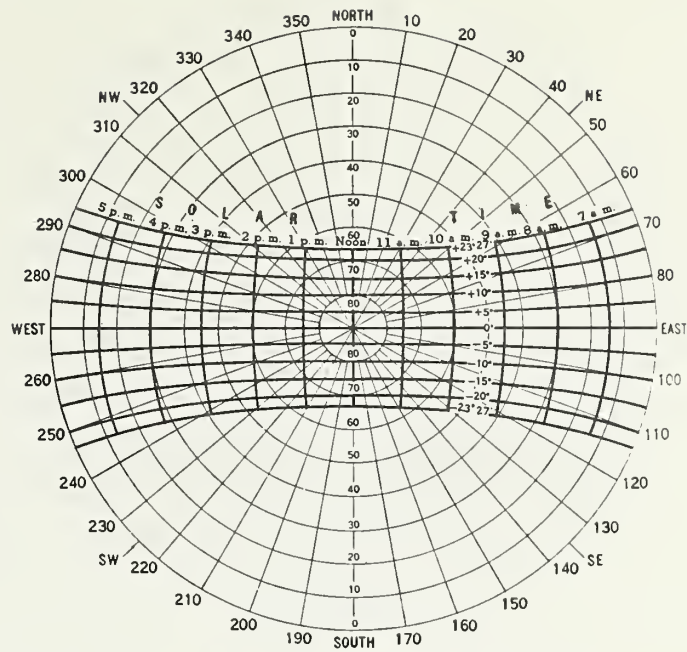


Figure 51.—Solar altitude and azimuth for selected days of the year at 0 degrees north latitude.

10° N.

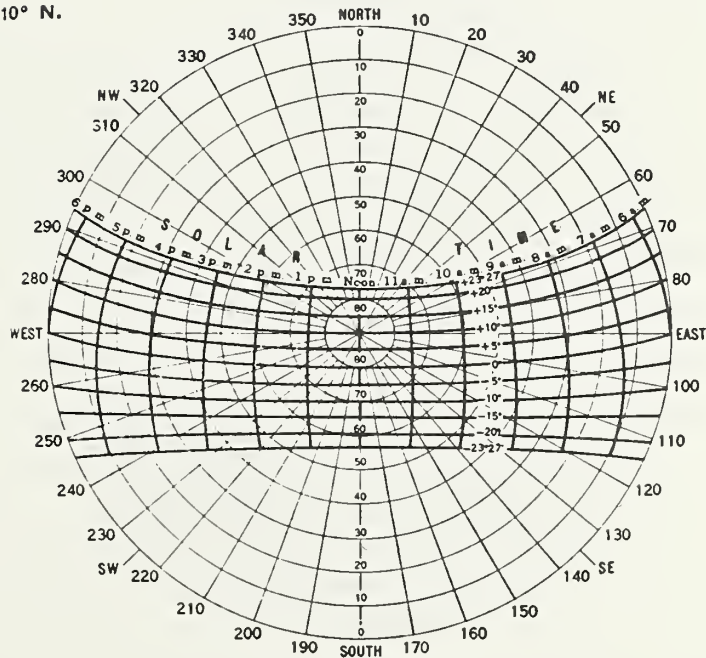


Figure 52.—Solar altitude and azimuth for selected days of the year at 10 degrees north latitude.

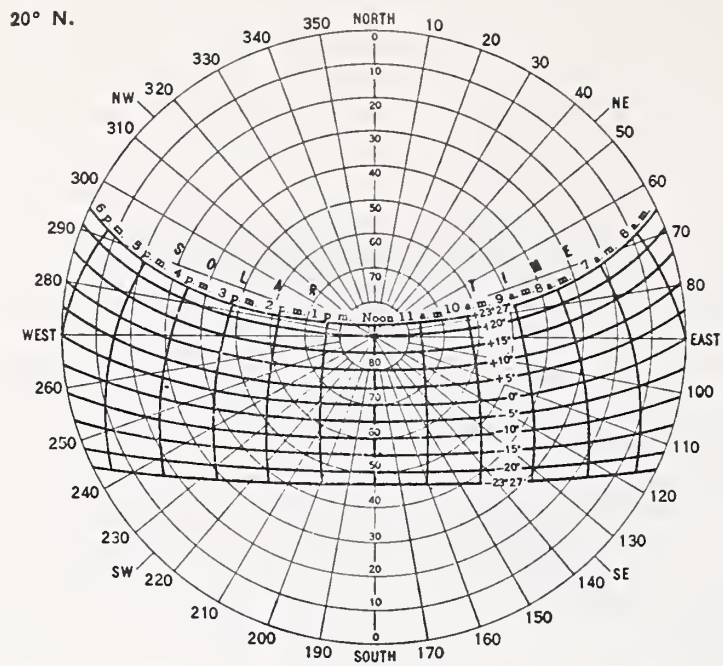


Figure 53.—Solar altitude and azimuth for selected days of the year at 20 degrees north latitude.

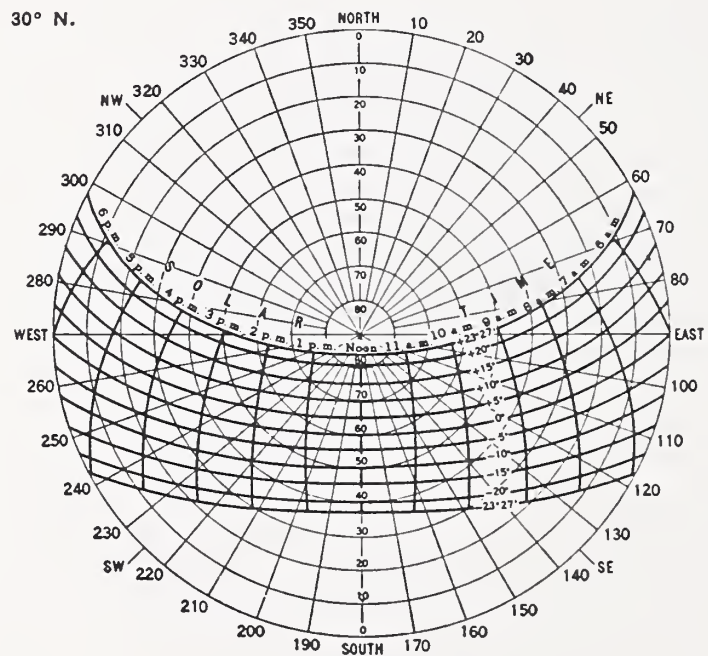


Figure 54.—Solar altitude and azimuth for selected days of the year at 30 degrees north latitude.



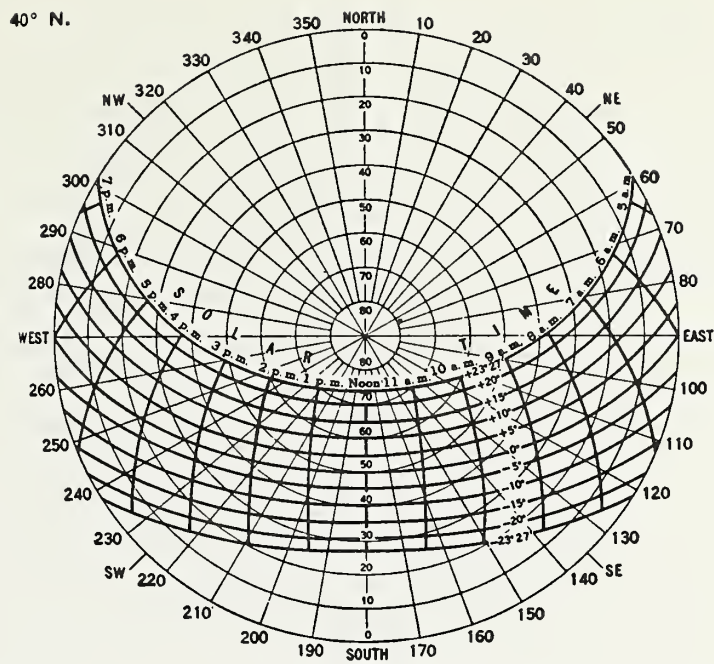


Figure 55.—Solar altitude and azimuth for selected days of the year at 40 degrees north latitude.

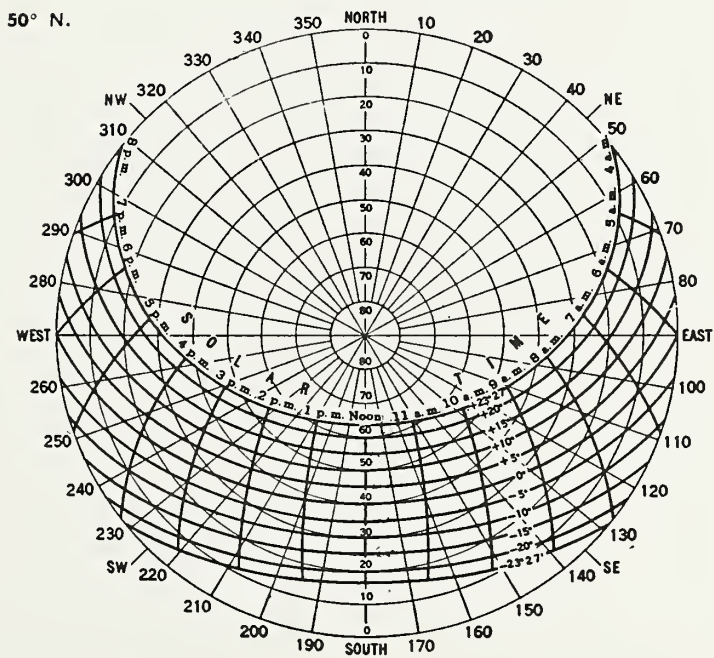


Figure 56.—Solar altitude and azimuth for selected days of the year at 50 degrees north latitude.

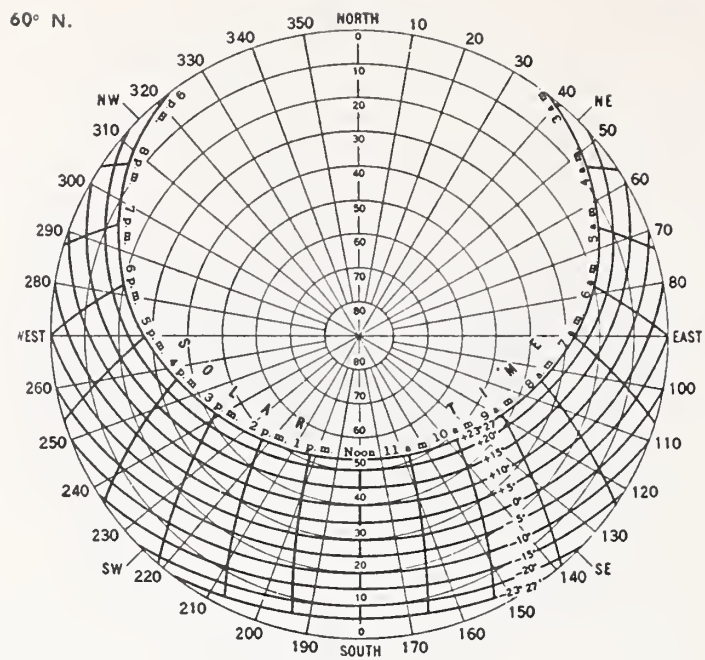


Figure 57.—Solar altitude and azimuth for selected days of the year at 60 degrees north latitude.





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Buffo, John, Leo Fritschen, and James Murphy

1972. Direct solar radiation on various slopes from 0° to 60° north latitude. USDA Forest Serv. Res. Pap. PNW-142, 74 p., illus. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

Direct beam solar radiation is presented in graphical and tabular form for hourly, daily, and yearly values for seven slopes on each of 16 aspects from the Equator to 60 degrees north in 10-degree increments. Theoretical equations necessary for the calculations are given. Solar altitude and azimuth during the day and year are also presented for the same latitudes.

Keywords: Direct solar radiation, solar radiation, slopes, aspects.

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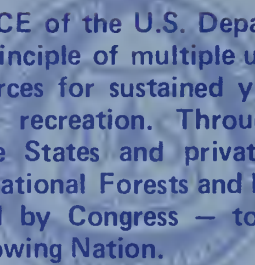
The mission of the PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION is to provide the knowledge, technology, and alternatives for present and future protection, management, and use of forest, range, and related environments.

Within this overall mission, the Station conducts and stimulates research to facilitate and to accelerate progress toward the following goals:

1. Providing safe and efficient technology for inventory, protection, and use of resources.
2. Development and evaluation of alternative methods and levels of resource management.
3. Achievement of optimum sustained resource productivity consistent with maintaining a high quality forest environment.

The area of research encompasses Oregon, Washington, Alaska, and, in some cases, California, Hawaii, the Western States, and the Nation. Results of the research will be made available promptly. Project headquarters are at:

Fairbanks, Alaska	Portland, Oregon
Juneau, Alaska	Olympia, Washington
Bend, Oregon	Seattle, Washington
Corvallis, Oregon	Wenatchee, Washington
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